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Clara Borges Perera

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Dissertação orientada pelo Prof Doutor Leonel Serrano Gordo (FCUL), e pela Doutora Mª Teresa García Santamaría (IEO), coadjuvada por Abdelmalek Faraj (INRH)

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Abstract

Black scabbardfish (*Aphanopus carbo* Lowe, 1839) is a benthopelagic species from the Family *Trichiuridae* that presents a global distribution and is object of an increasing commercial interest. Thus, this study seeks to contribute to the knowledge of the biology of *A. carbo* distributed in the Norwest Africa, and also helping in the understanding of this species in a more global level. In this work the following aspects are focussed: spatial distribution, size and sex structure, maturity, length-weight relationship and growth, in the area between Tangier and Cape Blanc (35ºN-21ºN).

In a general way, *A. carbo* is distributed between 700 and 1 700 m, although it was more abundant between 800 and 1 400 m, diminishing progressively with depth. The highest captures were obtained between 1 000 and 1 200 m. Regarding size distribution, a bimodal distribution in all the study area was observed, occurring a general trend of size increase with depth, being the mean length of females larger than males.

Concerning proportion of sexes, females were always more numerous than males in all the study area. Regarding maturity, percentages of spawning individuals were always superiors in males, what could indicate an advance of males in the spawning period in relation to females. In accordance with the high percentages of resting, pre-spawning and spawning individuals and the low percentages of post-spawners found in the study period (November), it could be said that spawning in this area would probably begin in the early December.

The analysis of the length-weight relationship showed a positive allometry in this species. On the other hand, females always reached higher size and weight than males. Finally, from the results obtained in the study of the age and growth the following parameters were estimated: for males, L_∞=119 cm, K=0.469 year^{-1} and t_0=-0.385 year; females: L_∞=125 cm, K=0.377 year^{-1} and t_0=-0.850 year; and sexes combined: L_∞=122 cm, K=0.415 year^{-1} and t_0=-0.645 year.

Key-words: *Aphanopus carbo,* black scabbardfish, Northwest Africa, distribution, biology.

Resumo

O peixe espada-preto (*Aphanopus carbo* Lowe, 1839) é uma espécie bentopelágica pertencente à Família *Trichiuridae* que apresenta uma distribuição global e com um interesse comercial crescente. Por esta razão, este estudo pretende contribuir para aumentar o conhecimento da biologia de *A. carbo* no noroeste de África (entre Tânger e Cabo Branco (35ºN-21ºN)) , acrescentando assim mais informação para uma área de que não se dispunha de dados. Neste trabalho abordam-se aspectos relacionados com a distribuição espacial, estrutura por sexo e comprimento, maturação sexual, relação comprimento-peso e idade e crescimento .

De uma maneira geral, *A. carbo* distribui-se entre 700 e 1 700 m, ainda que tenha sido mais abundante entre 800 e 1 400 m, diminuindo a abundância progressivamente com a profundidade. As maiores capturas foram obtidas entre os 1 000 e 1 200 m. Relativamente à distribuição de comprimentos, observou-se uma distribuição bimodal em toda a zona de estudo, com uma tendência geral do aumento do comprimento com a profundidade, sendo normalmente o comprimento médio das fêmeas superior ao dos machos.

No que se refere à proporção de sexos, as fêmeas foram sempre mais numerosas do que os machos em toda a área de estudo. Com respeito à maturação sexual, as percentagens de machos em postura foram sempre superiores às fêmeas, o que poderá indicar um desenvolvimento mais precoce dos mesmos no período de reprodução. As altas percentagens de indivíduos em estado de repouso, pré-postura e postura, e as baixas percentagens em estado de pós-postura encontrados na época de estudo (Novembro), poderá significar que a postura, nesta zona, iniciar-se-á provavelmente em princípios de Dezembro.

A análise da relação comprimento-peso revelou a existência de uma alometria positiva nesta espécie. Por outro lado, as fêmeas atingiram sempre maior comprimento e peso do que os machos. Finalmente, dos resultados obtidos no estudo da determinação da idade e crescimento estimaram-se os seguintes parâmetros: para machos, L_∞=119 cm, K=0.469 ano $^{-1}$ e t_0=-0.385 ano; fêmeas: L_∞=125 cm, K=0.377 ano^{-1} e t_0=-0.850 ano; e totais, L_∞=122 cm, K=0.415 ano^{-1} e t_0=-0.645 ano.

Palavras-chave: *Aphanopus carbo*, peixe-espada-preto, Noroeste de África, distribuição, biologia.

Resumen

El sable negro (*Aphanopus carbo* Lowe, 1839) es una especie bentopelágica perteneciente a la Familia *Trichiuridae* que presenta una distribución global y de interés comercial creciente. Por esta razón, este estudio pretende contribuir a aumentar el conocimiento de la biología de *A. carbo* distribuido en el noroeste africano, al tiempo que ayudar a la comprensión de esta especie a un nivel más global. En este trabajo se abordan aspectos como la distribución espacial, estructura por sexo y talla, madurez, relación talla-peso y crecimiento, dentro del área comprendida entre Tánger y Cabo Blanco (35ºN-21ºN).

De manera general, *A. carbo* se distribuye entre 700 y 1 700 m, aunque fue más abundante entre 800 y 1 400 m, disminuyendo progresivamente con la profundidad. Las mayores capturas fueron obtenidas entre los 1 000 y 1 200 m. Respecto a la distribución de tallas, se observó una distribución bimodal en toda la zona de estudio, además de una tendencia general al aumento de la talla con la profundidad, siendo normalmente la talla media de las hembras superiores a la de los machos.

En lo que se refiere a la proporción de sexos, las hembras fueron siempre más numerosas que los machos en toda el área de estudio. Respecto a la madurez, los porcentajes de individuos en puesta fueron siempre superiores en machos, lo que podría indicar un avance de los machos en el periodo de reproducción, en relación a las hembras. De acuerdo con los altos porcentajes de individuos en estado de reposo, pre-puesta y puesta, y los bajos porcentajes en estado de post-puesta encontrados en la época de estudio (Noviembre), podría decirse que la puesta en esta zona se iniciaría probablemente a principios de Diciembre.

El análisis de la relación talla-peso puso de manifiesto una alometría positiva en esta especie. Por otra parte, las hembras alcanzaron siempre mayor talla y peso que los machos. Finalmente, de los resultados obtenidos en el estudio de la determinación de la edad y crecimiento se estimaron los siguientes parámetros para machos: L_∞=119 cm, K=0.469 año $^{-1}$ y t_0=-0.385 año; hembras: L_∞=125 cm, K=0.377 año $^{-1}$ y t_0=-0.850 año; y totales: L_∞=122 cm, K=0.415 año $^{-1}$ y t_0=-0.645 año.

Palabras clave: *Aphanopus carbo,* sable negro, África Noroeste, distribución, biología.

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1. INTRODUCTION

Black scabbardfish (*Aphanopus carbo* Lowe, 1839) is a deep-water species from the Family *Trichiuridae*. It's a benthopelagic species living over continental slopes, seamounts and ocean ridges.

This species has been caught by longline in Madeira since the end of the XIX century and more recently also in mainland Portugal (since the 80' decade of the XX century). In other European countries (U.K., France and Ireland) it has been landed since 1985 as a by-catch of deep-water species trawl fisheries targeting mainly the grenadier, blue ling and deep-water sharks (Nakamura & Parin, 1993; Anon., 2004).

The black scabbardfish is not, at the moment, a target species of the Spanish fishing industry (Anon., 2000a). Spain only has had remarkable catches in the sub-area XII (Hatton Bank) where 165 t in 2004 and no one in 2005 were fished in mixed bottom trawl fisheries and hook fisheries, and in hook directed fisheries (Anon., 2006).

Global catches evolution according to the F.A.O. (Food and Agriculture Organization of the United Nations) during the period 1985-2005 has oscillated between 5 000 t (1985) and 12 000 t (2005); although during this period catches have not followed a defined pattern. From 1985 (5 000 t) to 1993 (13 000 t) a constant and progressive increase in the number of captured tons is observed. After this year the catches decrease to 9 000 t, except in 1996 that reach almost 14 000 t. After 2000, the catches seem to recover and in 2002 reach the 15 000 t, descending to 12 000 t in 2005 (Figure 1.1).

Due to the decreasing trend in the landings, especially in the northern European countries, the ICES (International Council for the Conservation of the Sea) has recommended important reductions in the North zone, whereas the situation in the Portuguese fishery seems to be in better conditions (Anon., 2002).

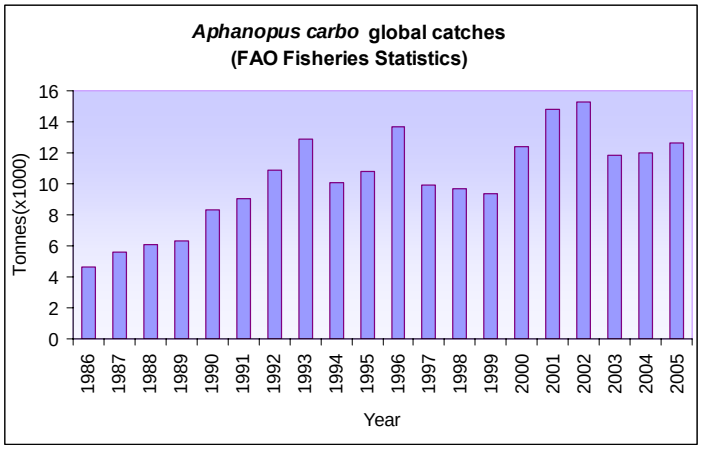

Figure 1.1.- Global evolution in catches of black scabbardfish.
Source: FAO Fisheries Statistics. www.fao.org

These numbers give an idea of the economic and fishing importance that has been acquiring this species in the last decades. Nevertheless, in spite of their increasing interest, not so much is known on its vital cycle.

Most of the studies on this species have mainly focused on its distribution (Maul, 1948; Tucker & Palmer, 1949; Templeman & Squires, 1963; Blacker, 1967; Bone, 1971; Fitch & Gotshall, 1972; Piotronski, 1981 *in* Morales-Nin & Sena-Carvalho, 1996), anatomy and general biology (Tucker, 1950; Holl & Meinel, 1968; Blaxter *et al*., 1971; Parin & Becker, 1972; Zilanov & Shepel, 1975; Howe *et al*., 1980 (*in* Morales-Nin & Sena -Carvalho, 1996), and others. Nevertheless, investigations made on age and growth are scarce, between them: Carvalho, 1988; Morales-Nin & Sena-Carvalho, 1996; Morales-Nin, 1999; Anon., 2000a; Carvalho, 2001; Morales-Nin *et al.*, 2002; Swan *et al* ., 2003; Barreto, 2005; Vieira *et al.*, 2006; Pajuelo *et al*., 2008 .

1.1. Objectives

The main objective of this study is to contribute to the knowledge of the biology and distribution of the black scabbardfish (*Aphanopus carbo*) in the North West African waters.

The distribution and abundance of this species will be analyzed in the study area, as well as its length distributions by depth, length-weight relationship, sex-ratio, sexual maturity state, and age and growth determination.

1.2. Structure of the study

The analysis and the results for the attainment of the objectives previously described are presented in conclusive chapters with the following structure:

- Diagnosis, description and distribution of the species
- Geological and oceanographic characteristics of the study area
- Characteristics and origin of the samples
- Geographical and bathymetrical distribution
- Spatial and temporary abundance
- Length distribution by depth and geographical area
- Biological parameters: sex-ratio, maturity stages, length-weight relationship and growth (measurements and weights of the otoliths, age reading criteria, age-length key and growth parameters estimation)
- Conclusions
- Acknowledges
- References

In addition, this study presents an Annex including a relation of focused studies on this species based on Gordon *et al*. (1999).

2. SPECIES GENERALITIES

Photography 2.1.- *Aphanopus carbo*. (Author: A. Sancho)

2.1. Diagnosis

The systematic position of this species following Nakamura & Parin (1993) is:

Kingdom: Animalia
Phylum: Chordata
Subphylum: Vertebrata
Superclass: Osteichthyes
Class: Actinopterygii
Subclass: Neopterygii
Infraclass: Teleostei
Superorder: Acanthopterygii
Order: Perciformes
Suborder: Scombroidei
Family: Trichiuridae
Subfamily: Aphanopodinae
Genus: Aphanopus Lowe, 1839
Species: *Aphanopus carbo* (Lowe, 1839)

2.2. General characteristics

Black scabbardfish was first time described in Madeira in 1839 by Richard Thomas Lowe, an English naturalist who lived in the island during 50 years. As it has been said previously, it is a deep-sea fish that lives in continental shelf, submarine mountains and oceanic ridges, with a global geographic distribution.

Its Latin name, *Aphanopus carbo*, makes reference to the absence of "extremities" and the black colour that shows. Its common name, in Spanish (sable negro) and in other languages (peixe espada preto, in Portuguese), makes reference to its morphology and its predator nature.

Black scabbardfish has an extremely elongated body with a large snout and carnivorous fang-like teeth. It is coppery black in colour and its gills cavities and mouth are also black. Once it has attained full growth, black scabbardfish can measure up to 140 cm (Madeira waters) (Morales-Nin & Sena-Carvalho, 1996) and within the frame of APHACARBO Project it has been registered individuals with almost 3 kg weight.

In general terms, the information available on its biology and vital cycle, shows that its first maturity length is 102.8 cm (Bordalo- Machado *et al*., 2001). Some authors consider that, due to the fact of being a deep-water species, its recovery capacity is very low. Thus, to duplicate population number it would be necessary between 4, 5 and 14 years (K=0.11) (Nakamura & Parin, 1993). Nevertheless, Morales-Nin & Sena-Carvalho (1996) define black scabbardfish like a species with a relatively fast growth that lives up to 8 years.

In Madeira waters, the spawning period occurs from October to February, being the smaller individuals in ripe condition between October and early December; and those individuals of larger length, between January and February (Bordalo-Machado *et al*., 2001).

In Icelandic waters, spent individual have been observed between January and March (Magnusson & Magnusson, 1995), which indicates that this species also reproduces in waters of the North Atlantic. In West British Islands spawning period has been observed between November to April, in depths between 700 to 900 m (Nakamura & Parin, 1993).

Spawners have never been captured either in NW Scotland or Portugal Mainland, although in Sesimbra (Portugal Mainland) some pre-spawning individuals were found (Bordalo-Machado *et al*., 2001). In Scotland only some individuals in initial stages of development were recorded.

Some scientists think most of deep-sea species cannot even support a moderate commercial exploitation, since are generally species of slow growth and long life that only produce small amount of eggs. In this sense, the fact of being a highly effective predator could explain, in part, its resilience.

2.3. General distribution

This species presents, in geographical terms, a global distribution. During most XIX and XX century it was considered exclusive of Madeira. Nevertheless, later it was discovered in places like South Ireland and even, Japan.

It has been recorded in the Atlantic Ocean, the Indian Ocean and the Pacific Ocean, living mainly continental slope until the 1 700 m of depth (Bordalo-Machado *et al*., 2001). At night it migrates to surface to feed on crustaceans, squids and other fish, and later descend before dawn.

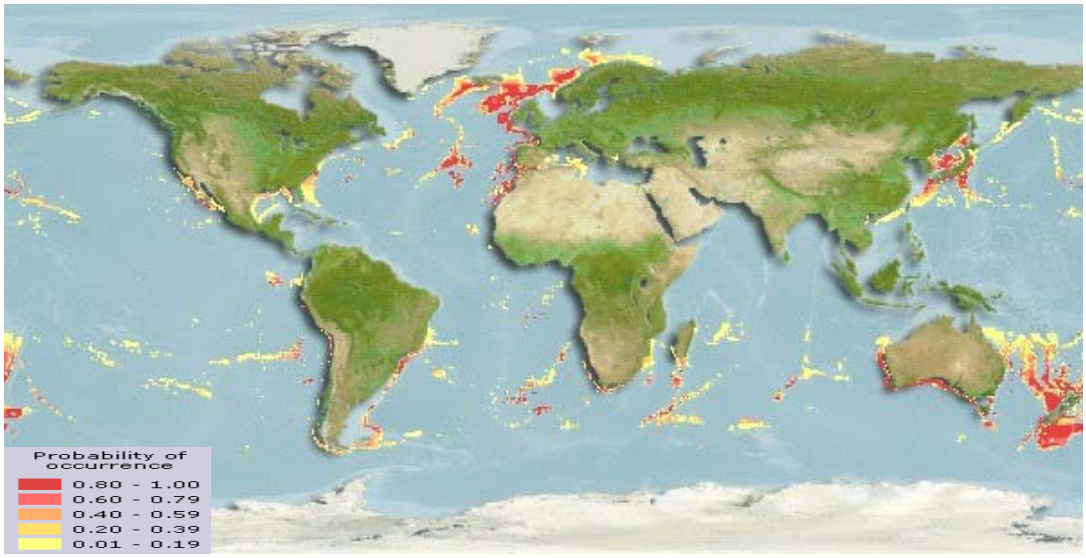

Figure 2.1.- Black scabbardfish distribution. Source: FishBase (www.fishbase.org)

In the NE Atlantic, the presence of small and big individuals in Madeira and intermediate individuals in Sesimbra (Portugal Mainland) suggests that black scabbardfish can have more than one stock, or if a single stock exists, then migrations will occur. If the case of the latter hypothesis, migrations towards North (Reikjanes Ridge, Rockall Trough) would be for trophic purposes (Morales-Nin *et al*., 2002), returning the individuals southwards to begin their reproduction (Bordalo-Machado, 2001).

3. STUDY AREA

The main geological and oceanographic characteristic of the study area are the following (Sanz & Meiners, *in* Ramos *et al*., 2005).

The Moroccan Atlantic continental margin is a passive margin due to the Atlantic opening between African and North American Plates. Such tectonic heredity processes induced the appearance of shearing corridories and a segmentation of the margin. There are three main structural domains: anti-atlasic and le prolongation Saharan, atlasic and plateau, rifain (Figure 3.1).

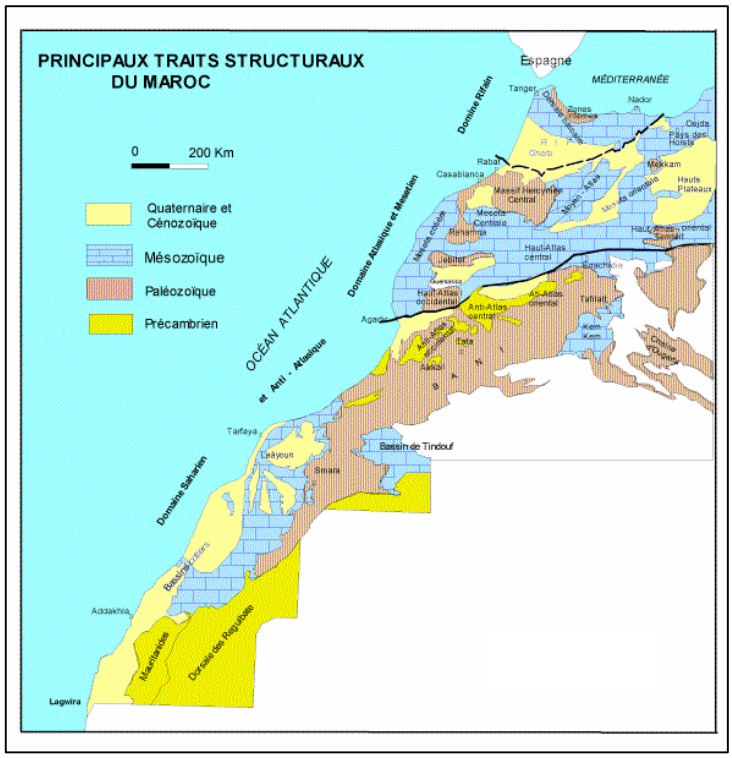

Figure 3.1.- Main structural domains in the study area (Sanz, 2005)

The Atlantic coast of Morocco is under influence of high subtropical pressure system of Azores and low pressure system related to the Intertropical Convergence Zone (ITCZ). It is part of the NW system of the African upwelling, which is one of the four major upwellings induced by wind in the world oceans (Kearns & Carr, 2003).

Azores Current (flows towards East) is the main current that recirculates in the Northeast Atlantic subtropical gyre. West Madeira, Azores Current turns towards

south and get divided. Its easternmost branch reaches African coasts, becoming in the Canary Current (Stramma & Siedler, 1988; Klein & Siedler, 1989; Siedler & Onken, 1996; Alves & Colin de Verdière, 1999) (Figure 3.2).

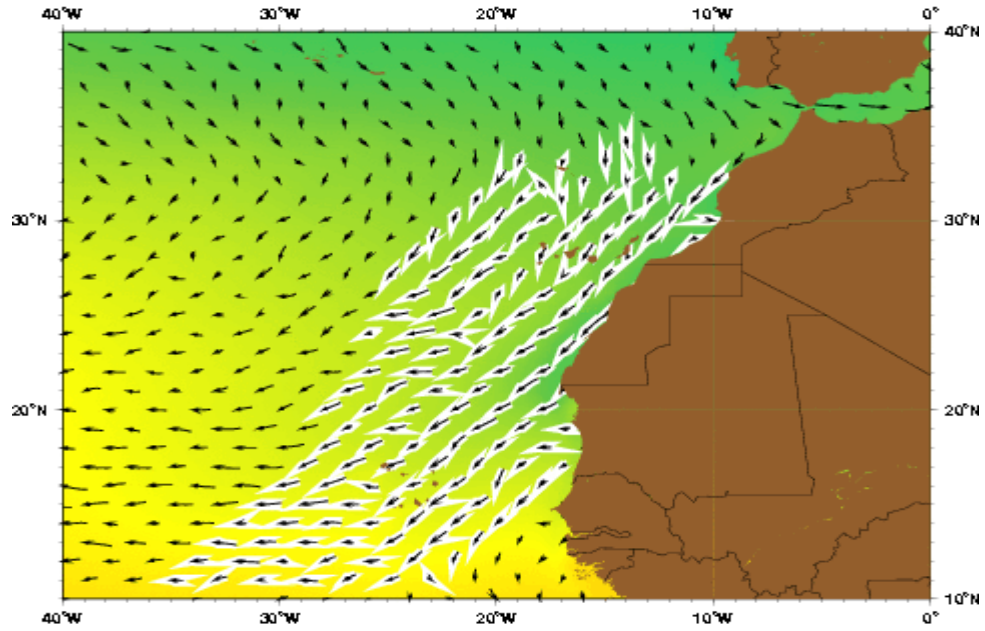

Figure 3.2.- The Canary Current. *Source*: Gyory *et al*. (2005)

The currents system throughout NW African coast includes, in addition to the Canary Current (superficial), a persistent submarine current that flows towards north, parallel to the African slope and sinks as latitude increases, reducing progressively its speed (Mittelstaedt, 1982). This submarine current has an approximated width of 30-60 km and a vertical extension of several hundreds of meters (Barton, 1989). During periods of locally weak winds, north submarine current can reach surface and extend on the continental shelf (Clarke, 1989; Mittelstaedt, 1991; Knoll *et al*., 2002).

Upwelling waters from NW African coast come from different sources. South of Cape Blanc (21ºN), coastal waters are constituted predominantly by ACSA (rich in nutrients and low salinity) that arises surface from 100-200 m depth. Whereas to north of Cape Blanc, upwelling waters belong to ACNA water mass (less rich in nutrients and saltier) that came from 200-300 m depth. Both water masses are originally of sub-superficial type. The two upwelling regions of different water masses, are separated by a transition area around Cape Blanc (Fraga, 1974;

Tomczak, 1978; Manríquez & Fraga, 1982) that correspond to a noticeable front with a temperature contrast and salinity up to 3ºC and 1 ups (Elmoussaoui *et al*., 2003).

Upwelling events are developed in coastal band of approximately 50 km wide, mainly on continental shelf (van Camp *et al.*, 1991) and in pulses of 5-10 days with a phase angle with variations in local winds, some hours in superior layers movements of the platform and a day in complete water column (Badab Dagon, 1980).

Mesoscale filaments and gyres are formed by capes in African coast that prevent local winds and coastal circulation, causing a divergent additional flow. West Cape Ghir appears one of the most important filament formation areas of the Moroccan coast (it is a semi-permanent phenomenon). It is particularly intense in summer and autumn and extends several hundreds of kilometres sea inside (van Camp *et al*., 1991; Nykjaer & van Camp, 1994; Hagen *et al*., 1996; Hernández-Guerra & Nykjaer, 1997; Barton, 1998).

4. SAMPLES AND SAMPLING

4.1. Origin

The analyzed samples at this work come from three deep demersal resources trawl surveys (Figure 4.1), developed within the bilateral cooperation framework between Spain and Morocco. The scientific coordination was carried out by the Instituto Español de Oceanografía (IEO) and the Institut National de Recherches Halieutiques of Morocco (INRH).

- Cruise *MAROC 0411*

Prospected area: from Tanger (35ºN) to Agadir (30ºN)
Date: 13 November – 14 December, 2004
Scientific Leader: Ana Ramos (IEO) and Abdelmalek Faraj (INRH)
Participating Scientists: 17
Depth: 500 – 2 000 meters
Stations: 88
Trawling duration: 1 hour

- Cruise *MAROC 0511*

Prospected area: from Agadir (30ºN) to Cape Boujdour (26ºN)
Date: 12 November – 14 December, 2005
Scientific Leader: Carlos Hernández (IEO) and Abdelmalek Faraj (INRH)
Participating Scientists: 18
Depth: 500 – 2 000 meters
Stations: 95
Trawling duration: 1 hour

- Cruise *MAROC 0611*

Prospected area: Cape Boujdour (26ºN) to Cape Blanc (21ºN)
Date: 12 November – 14 December, 2006
Scientific Leader: Carlos Hernández (IEO) and Abdelmalek Faraj (INRH)
Participating Scientists: 18
Depth: 200 – 2 000 meters
Stations: 99
Trawling duration: 1 hour

Figure 4.1.-Cover Map of Cruise *Maroc 0411*, *Maroc 0511* and *Maroc 0611*. *Source*: Google Earth Software 2005

The cruises were made on board of the Spanish R/V *Vizconde de Eza* (Photography 4.1) whose main technical characteristics are the following: length overall (53 m), breadth (13 m), gross registered tonnage (1 400 GRT), power (1 800 hp), cruise speed (13 knots), radio indicative (EAXB), having in addition systems to aid navigation, scientific equipment, support investigation systems, as well as ample dependencies to the scientific work development.

Photography 4.1.- R/V Vizconde de Eza. *Source*: Ramos *et al*. (2005)

In relation to the continental shelf, deep resources have been little exploded, among other reasons, the ignorance on stocks and biology of the deep species, to the low density of most of them and to the unsustainability of these stocks (Gage & Tyler, 1991) (*in* Ramos *et al*., 2005). The main objective of these cruises was the prospection and evaluation of the existing fishing resources in the slope and abyssal zone between 500 and 2 000 meters, and as principal tasks estimation of yields and densities in number and weight of all the demersales and benthonic species, specially of the species with commercial value like black scabbardfish (*Aphanopus carbo*); length composition of all fish species, crustaceans and molluscs; and biological samplings of the fish target species and invertebrates with commercial interest.

The used gear during the cruises was a "*Lofoten*" trawl gear, 17.70 and 5.5 horizontal and vertical meters open, respectively, and cod mesh of 35 mm. The equipment was provided with 250 m warp rope to trawler; a trawl train with 14'' steel balls, with 32 cm of diameter that facilitate trawling on difficult lands at great depth; and doors with 850 k. The details of the gear appear in Photography 4.2.

(a)

(b)

(c)

(d)

Photography 4.2.- *Lofoten* trawling net (a) and equipment details (b) balls train (c) doors and (d) cod end. *Source*: Ramos *et al*. (2005)

The evaluation was made by swept area method and a sampling stratified random scheme with a geo-statistical approach.

Stations characteristics where target species of this study has been captured (*Aphanopus carbo*) are shown in tables 4.1, 4.2 and 4.3 (years 2004, 2005 and 2006, respectively).

Table 4.1.- Characteristics of the stations (latitude, longitude, mean depth) with catches of *Aphanopus carbo*. Year: 2004

Station	Latitude N	Longitude W	Depth (m)	Catch (Kg)
4	35º 25′ 54″	6º 58′ 27″	874	1,3
6	35º 21′ 03″	7º 22′ 56″	1298	2,9
7	35º 21′ 40″	7º 30′ 50″	1422	9,3
8	35º 44′ 13″	7º 23′ 26″	1296	9,1
9	35º 49′ 21″	7º 25′ 29″	1213	2,4
10	35º 36′ 19″	7º 31′ 56″	1319	12,1
11	35º 55′ 42″	7º 20′ 52″	995	13,9
12	35º 46′ 45″	7º 10′ 21″	1190	24,4
13	35º 48′ 11″	7º 01′ 26″	1064	7,2
18	35º 39′ 32″	6º 56′ 39″	1019	10,1
19	35º 32′ 35″	7º 08′ 47″	1172	22,3
20	35º 36′ 01″	7º 23′ 27″	1244	8,6
21	35º 27′ 57″	7º 11′ 38″	1163	3,8
22	35º 22′ 22″	7º 09′ 21″	1126	6,7
23	35º 06′ 54″	7º 13′ 23″	1082	8,1
24	35º 05′ 48″	7º 23′ 14″	1264	4,1
25	35º 11′ 02″	7º 39′ 46″	1419	2,2
32	34º 52′ 26″	7º 21′ 53″	1409	4,1
33	34º 58′ 58″	7º 23′ 35″	1242	12,4
36	35º 07′ 10″	7º 01′ 30″	903	7,6
42	34º 55′ 52″	6º 55′ 07″	755	0,3
43	34º 24′ 53″	7º 03′ 22″	933	7,5
45	34º 27′ 13″	7º 22′ 34″	1218	22,8
48	34º 19′ 53″	7º 26′ 02″	842	1,6
49	34º 20′ 24″	7º 35′ 10″	1019	18,5
50	34º 15′ 25″	8º 04′ 22″	1555	4,4
52	34º 08′ 39″	8º 04′ 05″	1024	5,7
57	33º 47′ 28″	8º 40′ 32″	830	2,4
59	33º 37′ 33″	8º 58′ 58″	912	0,8
60	33º 39′ 12″	9º 01′ 03″	1166	6,4
61	33º 38′ 07″	9º 15′ 57″	1689	1,8
62	33º 25′ 25″	9º 23′ 39″	911	26,5
69	32º 36′ 39″	9º 44′ 07″	1144	37,4
70	32º 25′ 23″	9º 51′ 40″	1052	26,1
71	31º 58′ 22″	10º 11′ 40″	1245	42,0
73	31º 30′ 46″	10º 18′ 39″	892	27,5
75	31º 30′ 03″	10º 39′ 40″	1032	19,1
76	31º 35′ 24″	10º 50′ 05″	1371	2,4
79	31º 16′ 59″	10º 44′ 27″	844	35,8
80	31º 10′ 32″	10º 45′ 04″	975	107,5
81	31º 12′ 09″	10º 52′ 24″	1148	58,9
85	30º 56′ 38″	10º 37′ 44″	1168	27,6
87	30º 42′ 40″	10º 21′ 35″	863	12,0
89	30º 14′ 45″	10º 28′ 28″	1354	5,6
90	30º 12′ 35″	10º 26′ 23″	1165	24,3
91	30º 17′ 04″	10º 25′ 30″	1264	23,6
92	30º 21′ 28″	10º 15′ 51″	938	30,8
93	30º 14′ 28″	10º 14′ 36″	846	13,6

Table 4.2.- Characteristics of the stations (latitude, longitude, mean depth) with catches of *Aphanopus carbo*. Year: 2005

Station	Latitude N	Longitude W	Depth (m)	Catch (Kg)
2	30º 51' 47''	10º 36' 49''	1261	62,4
3	30º 52' 51''	10º 31' 28''	1015	105,8
7	30º 23' 10''	10º 13' 42''	885	34,4
8	30º 25' 41''	10º 21' 52''	1160	58,6
9	30º 15' 32''	10º 22' 32''	1207	32,9
10	30º 05' 29''	10º 28' 31''	1412	14,3
18	30º 04' 25''	10º 12' 22''	784	5,9
20	29º 54' 41''	10º 27' 02''	1253	27,6
21	30º 06' 00''	10º 41' 40''	1619	5,3
22	30º 00' 20''	10º 22' 32''	1336	33,0
29	29º 40' 19''	10º 38' 42''	1040	36,7
30	29º 39' 41''	10º 46' 19''	1198	10,5
31	29º 35' 17''	11º 01' 30''	1420	4,8
35	29º 28' 13''	11º 15' 22''	1420	1,8
39	29º 17' 38''	11º 35' 13''	1155	16,1
40	29º 21' 34''	11º 22' 34''	1195	14,7
41	29º 24' 40''	11º 27' 07''	1378	3,7
42	29º 27' 43''	11º 40' 35''	1570	2,1
45	29º 13' 18''	11º 50' 42''	1165	5,0
47	29º 11' 45''	11º 42' 50''	986	5,8
48	29º 12' 46''	11º 45' 54''	1078	20,5
49	29º 11' 47''	11º 58' 37''	1104	29,3
52	29º 10' 40''	12º 12' 34''	1145	20,4
54	28º 03' 59''	13º 25' 38''	1055	21,2
55	27º 52' 49''	13º 26' 26''	724	0,5
57	27º 34' 13''	13º 39' 20''	795	0,4
58	27º 32' 42''	13º 42' 32''	973	13,6
59	27º 23' 38''	13º 49' 26''	1291	15,3
60	27º 22' 20''	13º 44' 38''	980	19,9
61	27º 13' 34''	13º 49' 19''	1126	6,9
65	27º 08' 34''	13º 50' 10''	976	3,7
66	27º 06' 36''	14º 04' 20''	1282	12,9
67	26º 57' 27''	14º 03' 28''	814	0,4
69	26º 40' 36''	14º 33' 14''	1223	34,3
70	26º 32' 12''	14º 26' 26''	968	13,9
72	26º 58' 26''	14º 14' 47''	1251	13,4
74	26º 48' 00''	14º 15' 12''	1023	19,0
75	26º 44' 19''	14º 22' 25''	1068	22,0
76	26º 33' 21''	14º 33' 16''	1391	52,0
77	26º 37' 34''	14º 41' 31''	1346	27,0
78	26º 39' 46''	14º 45' 20''	1591	12,3
79	26º 32' 45''	14º 46' 37''	1018	41,4
82	26º 22' 50''	14º 54' 54''	883	16,2
84	26º 20' 44''	15º 01' 36''	912	1,8
86	26º 15' 48''	15º 09' 32''	843	8,4
89	26º 16' 14''	15º 17' 41''	1123	44,9
91	26º 12' 42''	15º 27' 44''	1311	16,8
92	26º 06' 50''	15º 26' 32''	847	13,6
93	26º 06' 25''	15º 35' 31''	1631	8,0
94	26º 03' 35''	15º 46' 25''	1413	3,6

Table 4.3.- Characteristics of the stations (latitude, longitude, mean depth) with catches of *Aphanopus carbo*. Year: 2006

Station	Latitude N	Longitude W	Depth (m)	Catch (Kg)
2	21º 11' 22''	17º 49' 39''	995	81,9
3	21º 13' 23''	17º 57' 04''	1300	5,8
5	21º 22' 20''	17º 58' 28''	1207	35,3
7	21º 24' 59''	17º 53' 15''	983	3,5
12	21º 38' 29''	17º 58' 23''	1255	13,3
16	21º 41' 13''	17º 50' 17''	1003	13,6
18	21º 52' 19''	17º 33' 02''	1089	6,3
19	21º 50' 12''	17º 37' 29''	1230	13,5
20	21º 53' 24''	17º 47' 46''	1561	1,6
23	22º 04' 35''	17º 49' 33''	1449	5,8
24	22º 07' 22''	17º 43' 16''	1188	17,3
25	22º 08' 44''	17º 32' 40''	906	0,3
31	22º 35' 46''	17º 26' 43''	1023	26,3
35	22º 44' 20''	17º 32' 43''	1325	19,4
36	22º 51' 52''	17º 21' 17''	875	13,2
42	22º 59' 29''	17º 37' 43''	1570	1,7
43	23º 01' 43''	17º 34' 16''	1390	13,3
44	22º 59' 28''	17º 22' 17''	889	9,2
45	23º 04' 44''	17º 20' 25''	1101	24,0
47	23º 12' 01''	17º 11' 35''	911	2,2
48	23º 13' 29''	17º 17' 42''	1142	17,2
49	23º 15' 13''	17º 23' 32''	1340	21,8
50	23º 26' 18''	17º 29' 14''	1469	1,8
51	23º 28' 25''	17º 16' 32''	966	5,0
55	23º 44' 31''	17º 27' 52''	1529	2,3
56	23º 40' 49''	17º 19' 46''	1153	33,4
62	23º 59' 32''	17º 10' 45''	1450	1,8
63	23º 56' 28''	17º 02' 33''	1054	1,6
66	24º 05' 14''	16º 55' 32''	908	2,0
68	24º 24' 32''	16º 43' 20''	1035	4,5
71	24º 07' 23''	16º 59' 44''	1124	20,6
72	24º 31' 26''	16º 51' 07''	1435	2,3
78	24º 37' 34''	16º 37' 41''	1041	4,5
79	24º 56' 31''	16º 38' 45''	1243	2,5
83	25º 02' 43''	16º 29' 43''	898	1,0
85	25º 12' 40''	16º 20' 20"	821	2,2
91	25º 33' 10''	16º 12' 44''	1285	10,0
92	25º 34' 27''	16º 08' 09''	957	0,3
100	25º 51' 47''	15º 49' 29''	885	1,2

4.2. Length sampling

After each trawl it was made a separation and quantification, in number and weight, of all the species pertaining to four great taxonomic groups: fishes, crustaceans, cephalopods and other benthonic invertebrates. In addition, length samplings for all the species were made.

In case of *Aphanopus carbo*, total length until the end of the tail was measured by an ictiometer graduated to millimetre, rounded down to nearest centimetre.

4.3. Biological sampling

Biological sampling consisted in data obtaining referred to:

- Total length: precision in mm
- Weight: precision to 1 g
- Sex: 1 (male), 2 (female), 3 (indeterminate)
- Maturity stage: scale from 1 to 5 (virgin, in repose, pre-spawning, spawning and post-spawning)
- Gonadal weight: precision to 0.1 g
- Otoliths extraction and preservation into labelled envelops

A total of 876 individuals were analyzed during these three cruises: 251 during cruise *MAROC 0411*, 358 in *MAROC 0511*, and 267 in *MAROC 0611*.

5. SPATIAL DISTRIBUTION

5.1. Introduction

In this chapter, bathymetrical (from 700 to 1 700 m depth) and geographical species distribution (from 35ºN to 21ºN) will be presented and analyzed.

5.2. Material and Methods

The catches were obtained in the three *MAROC* surveys during 2004, 2005 and 2006 and their analysis will permit to compare with the distribution of *Aphanopus carbo* in other areas where species has been recorded.

5.3. Results

Results of the nominal catches for the same depth strata in the study area are given in Figure 5.1.

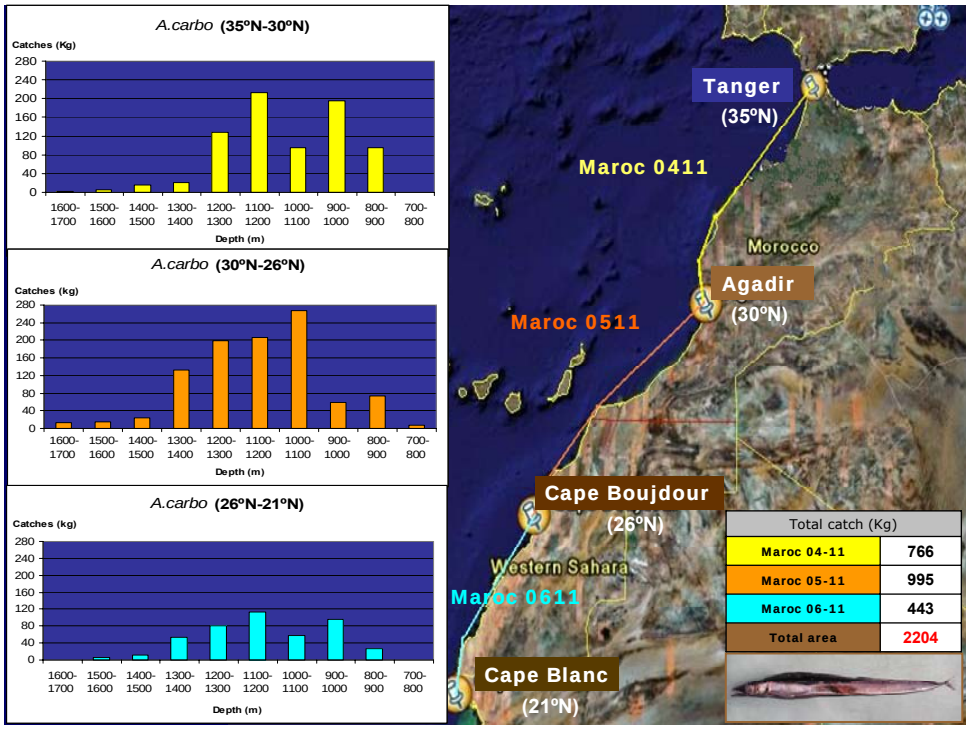

Figure 5.1.- Catches by depth in surveys *Maroc* 0411, *Maroc* 0511 and *Maroc* 0611

As it can be seen, in zone 35ºN-30ºN, catches were higher between 800 and 1 500 meters depth. At 700-800 m and deeper than 1 500 m catches were scarce

or almost null (0.3 Kg and 1.8 Kg respectively). Maximum value occurs at 1 100-1 200 meters (211.8 kg) followed by catches at 900-1 000 m (194.6 kg) and 1 200-1 300 m (127.9 kg).

Aphanopus carbo estimated biomass (calculated following the Swept area Method[1]) was 1 110 tons for this study area. However, and in spite of being frequent its appearances in the catches (54.5%), the species had a weak relative importance (3.3%) respect to other species with commercial value (Ramos *et al*., 2005).

Between 30ºN-26ºN, *A. carbo* was captured mainly between 800 and 1 600 meters. Catches were very scarce between 700-800 m (6.8 kg) although higher than in previous area. The maximum value was observed between 1 000-1 100 m (266.6 kg), decreasing gradually until 1400 m (132.5 kg). Deeper, its presence was very low but more significant that in the first studied zone. Between 800 and 1 200 m, *A. carbo* is one of the most usual species captured. Their biomass estimated was 1 198 t (Hernández *et al*., 2006).

Finally, between 26ºN and 21ºN, the catches in all depth ranges were significantly lower than in the two zones previously described. Between 700-800 m and 1 600-1 700 m no individuals of this species were captured. Its greater capture occurred between 1 100 and 1 200 meters depth (112.5 kg), decreasing gradually until 1 600 m (5.6 kg).

5.4. Discussion

Nakamura & Parin (1993) described this species as a wide-world benthopelagic species with a deep range from 200 to 1 600 meters. In the study area (35ºN to 21ºN), the highest catch was registered between 30ºN-26ºN (995 kg), followed by the 35ºN-30ºN zone (766 kg). The minimum value (443 kg) corresponded to the southern zone (26ºN-21ºN). *A. carbo* was distributed between 700 and 1 700 m. However, it was more abundant between 800 and 1 400 m, decreasing

[1] Each station gives a mean value of capture/biomass that is extrapolated to the total area of each stratum, to obtain an index of abundance that is proportional to the real abundance and their changes over time.

progressively towards deeper waters and practically was not captured between 700-800 m. The highest catches were obtained between 1 000 and 1 200 meters depth.

In waters off Canary Islands, *A. carbo* has been captured between 800 and 2 300 m, deeper than previous observation for this species. However, the zone of most frequent distribution was around 1 000 m as in our study area (Pajuelo *et al*., 2008).

Results of the longline surveys conducted by IPIMAR along the Portuguese continental coast showed that the distribution of black scabbardfish varies from 800 to 1 600 m (Anon., 2002). The most important fishery is located in grounds around Sesimbra (south Lisbon, Latitude 38º20´N) (Bordalo Machado *et al*., 2001) between 800 and 1 200 meters (Anon., 2002).

In other areas like Madeira, distribution range varies between 180 and 1 600 m, much wider than that for the Portuguese coast (1 000-1 600 m) (Morales-Nin & Sena-Carvalho, 1996). The highest abundance in Madeira occurs between 700 and 1 300 m associated to the "Mediterranean water" (characterized by low values of dissolved oxygen, a temperature of 8.5-10.5 ºC, very small salinity gradients and high nutrient values) (Leite, 1989). Density of this water mass is such that it forms a layer about 1 000 m depth and extends in a plume out into Atlantic Ocean. A component of this water mass extends northward into deep water off Portugal and can be detected in Porcupine Seabight and Rockall Trough. It is very probably found around Hatton Bank; although very unlikely to be found on the Reykjanes Ridge (Anon., 2000a).

In North Europe the species is more commonly found from 500 to 800 m (Ehrich, 1983; Bridger, 1978 *in* Bordalo-Machado, 2001). According to Zilanov & Shepel (1975), this species is distributed along entire continental slope of North Atlantic and is usually found at depth of 600-1 200 m and rarely at 400-450 m. These authors established that depth distribution depends on season of the year (summer and autumn at 600-800 m and deeper during rest of year). Templeman & Squires (1963) established that this species is found on western shelf of British

Isles at depth of 180 m. Finally, three *A. carbo* individuals were captured between 494 and 713 m in the Pacific Ocean (Fitch & Gotshall, 1972).

Bathymetrical distribution can be explained by the temperature surface waters when approaching the equator. This means that our species will be found in more superficial waters above 40ºN and in deeper waters as they move to the equator. On the other hand, its deeper distribution in the Canaries respect to Madeira may be due to a strategy of avoiding a habitat overlapping with the snake mackerel (Pajuelo *et al.*, 2008).

According to that, *A. carbo* is a species with a width geographical distribution and whose bathymetrical distribution does not follow a defined nor fixed pattern.

However, it is necessary to emphasize that in our study we do not have information near the coast or in the continental shelf because of the main objective of these surveys was the prospection and evaluation of the existing fishing resources in the slope and abyssal zone between 500 and 2 000 meters. That does not suppose non-existence of our species at these coastal zones, on contrary since we know certainly that it exists at more superficial depths those 500 meters.

On the other hand, although cruises have been carried out in the same month (November), we cannot discard possible effects of temporary variations along the different years (2004, 2005 and 2006).

6. SIZE AND SEX STRUCTURE

6.1. Introduction

In order to detect a possible bathymetrical (from 700 to 1 700 m) and geographical (35ºN-21ºN) segregation by size and/or by sex, an analysis of size and sex structure by depth strata of the catches was carried out.

6.2. Material and Methods

A total of 1 573 individuals were used in the study: 538 from North Zone (35ºN-30ºN), 633 from Central Zone (30ºN-26ºN) and 402 from South Zone (26ºN-21ºN). Differences in size frequency distributions of *A. carbo* by depth and latitude were analysed using a two-tailed Kolmogorov-Smirnov test for large samples with 2 cm range from 50 to 141 cm, performed for the best representative strata (800-900, 900-1 000, 1 000-1 100, 1 100-1 200 and 1 200-1 300 m) combinations. Critical values were obtained at the 0.05 level of significance using the Siegel and Castellar (1988) method.

Differences between mean length by depth strata for both, males and females were tested through an Analysis of Variance (Two-way ANOVA) (Zar, 1984) with a Bonferroni post test using GraphPad Prism version 4.00 for Windows.

Sex ratio was estimated by size, depth strata and geographical area. Results were tested using the chi-square analysis (Zar, 1984).

6.3. Results

6.3.1. *Size structure*

6.3.1.1. *Length distribution*

Length distributions of *A. carbo* caught in the three studied zones are presented in Table 6.1, 6.2 and 6.3 and Figure 6.1. As it can be seen, a bimodal distribution appears in all the areas but it is much more evident in the Central Zone. Following these results, the proportion of individuals smaller than 93 cm length (immature in our study) was very similar in both Central and South Zones (30%

and 26%, respectively). However, the number and proportion of these specimens in the South Zone was highest (63%). This fact is also shown in the mean length evolution by strata and geographical zone (section 6.3.1.2).

Table 6.1. Length distribution of *A. carbo* by depth strata in North Zone (35ºN-30ºN)

Length range (cm)	700 800 (m)	800 900 (m)	900 1000 (m)	1000 1100 (m)	1100 1200 (m)	1200 1300 (m)	1300 1400 (m)	1400 1500 (m)	1500 1600 (m)	1600 1700 (m)
50-51			1							
52-53										
54-55		1								
56-57										
58-59		1								
60-61	1	1								
62-63		4	1							
64-65		2	3							
66-67		3		1						
68-69		6	1							
70-71		9	2							
72-73		7	3							
74-75		6	4							
76-77		10	7							
78-79		10	1							
80-81		10	1							
82-83		13	3							
84-85		5	3		1					
86-87		8	5							
88-89		4	6		1					
90-91		7		3						
92-93		5	2	2						
94-95		6	6	2						
96-97		1	5	7		1		1		
98-99		1	4	3	2	2				
100-101		3	2	4	4	4				
102-103		2	7	7	5	2				
104-105		4	7	7	7	5	2			
106-107		1	11	6	16	6	1			
108-109			4	5	13	11			1	1
110-111		1	8	5	16	6				
112-113		1	7	4	9	7	5	2		
114-115		2	4	1	5	5		3		
116-117			8	2	13	4	2			
118-119			3	1	14	7		1		
120-121			8		4	6		1		
122-123			1		1	1				
124-125			2		2					
126-127			3	1	2				1	
128-129			2		1					
130-131			2	1						
132-133										
134-135										
136-137										
138-139										
140-141										
Total	**1**	**134**	**137**	**62**	**116**	**67**	**10**	**8**	**2**	**1**

Table 6.2. Length distribution of *A. carbo* by depth strata in Central Zone (30ºN-26ºN)

Length range (cm)	700 800 (m)	800 900 (m)	900 1000 (m)	1000 1100 (m)	1100 1200 (m)	1200 1300 (m)	1300 1400 (m)	1400 1500 (m)	1500 1600 (m)	1600 1700 (m)
50-51										
52-53										
54-55										
56-57										
58-59										
60-61		3	1							
62-63		5								
64-65		5								
66-67		16	2	1						
68-69	1	22								
70-71	1	12								
72-73	1	15	1							1
74-75	2	19	5	1						
76-77	2	16	1							
78-79		6								
80-81	1	2	3					1		1
82-83		3	2							
84-85	1	2								
86-87	2	1	1	1						
88-89		2		1						
90-91		1								
92-93		1	1	1						
94-95										
96-97		1	1	1						
98-99				3						
100-101		1	3	1	3	2	1	1		1
102-103				5	2	3	2	1		
104-105			3	12	1	2	2	1		
106-107		1	2	16	9	4	4			
108-109			1	20	15	9	4	2		1
110-111				25	13	10	7		1	
112-113			1	21	19	15	6	1		1
114-115		1	5	16	15	23	6	2		1
116-117			1	5	13	12	12	2	2	1
118-119			4	4	11	6	11		1	1
120-121			1	7	3	5		1		
122-123			1	4	3	5	2	1		
124-125			1	2	1	1	4			
126-127			1				1		1	
128-129					2				1	
130-131							1			
132-133										
134-135						1				
136-137										
138-139										
140-141										
Total	**11**	**135**	**42**	**147**	**110**	**98**	**63**	**13**	**6**	**8**

Table 6.3. Length distribution of *A. carbo* by depth strata in South Zone (26ºN-21ºN)

Length range (cm)	700-800 (m)	800-900 (m)	900-1000 (m)	1000-1100 (m)	1100-1200 (m)	1200-1300 (m)	1300-1400 (m)	1400-1500 (m)	1500-1600 (m)	1600-1700 (m)
50-51										
52-53										
54-55										
56-57										
58-59		2								
60-61		7		2	1					
62-63		7	2	3						
64-65		8		4	1					
66-67		9	6	4		1				
68-69		7	4	5						
70-71		9	2	6	1					
72-73		6	7	10	1	1				
74-75		6	8	8	2	1				
76-77		1	10	6						
78-79			6	8	2					
80-81			7	9						
82-83			6	4	4					
84-85			2	4	4	2				
86-87			2	5	4	3				
88-89				3		1	2			
90-91			2		1	8				
92-93					4	3	1			
94-95			1	2	8	4	2			
96-97				1	2	3	2	1		
98-99			1		2	5	5			
100-101					2	9	8	1	1	
102-103		1		1	4	2	3	1		
104-105					3	4	3	2		
106-107					3	3	3		1	
108-109				1	4	1	2			
110-111					4	2	3	1		
112-113				1	5	1	2		1	
114-115				1	6	1	1	1		
116-117				1	3		1			
118-119					2		1			
120-121					3	1				
122-123										
124-125					1					
126-127										
128-129										
130-131										
132-133										
134-135					1					
136-137										
138-139						1				
140-141										
Total		**63**	**66**	**89**	**78**	**57**	**39**	**7**	**3**	

In order to detect a possible trend in the bathymetrical distribution of this species, a graphic representation of the three main size categories (50-93 cm; 94-121 cm and 122-141 cm) by depth strata was made (Figure 6.1 A, B and C). As it can be seen, in the North Zone individuals from the first size category (between 50 and 93 cm) were the most abundant and occurred mainly in the lower depth strata, mainly between 800 and 1 000 m. As depth increases, the number of individuals decreases but increases the number of specimens belonging to the second size category (94-121 cm). Individuals larger than 122 cm (third size category) were the less numerous (Figure 6.1 A).

The Central Zone followed the same pattern found in North Zone but much more evidentiated. In fact, the lower depths (800 to 1 100 m) were characterised by the occurrence of smaller specimens (<93 cm) while, in depths greater than 1 000 m individuals between 94 and 121 cm, were more abundance (Figure 6.1 B). Once again, individuals above 122 cm were very scarce and occurred in different depths strata.

Regarding the South Zone, the largest individuals (122-141 cm) were practically absent in the catches. The majority of the individuals were included in the smallest range size (50-93 cm) but, differently of former zones, they were found in deeper waters (up to 1 300 m). The second size category was mainly found between 1 100 and 1 400 m (Figure 6.1 C).

Results of the Kolmogorov-Smirnov test on the comparison of the size structure from the same depth strata between North and Central Zones indicate that differences between 1 100-1 200 m and 1 200-1 300 m strata are not statistical significant ($D_{max} < 0.2087$ and $D_{max} < 0.1893$, respectively). However, in the comparison of 800 to 1 100 m depth strata statistically differences were found ($D_{max} > D_{0.05, (m,n)>25}$). In the South Zone, the differences between size structure of 900-1 000 m and 1 000-1 100 m; and 1 100-1 200 m and 1 200-1 300 m depth strata were not statistically significant ($D_{max} < 0.0795$ and $D_{max} < 0.2430$, respectively). The remaining depth strata were statistically different ($D_{max} > D_{0.05, (m,n)>25}$).

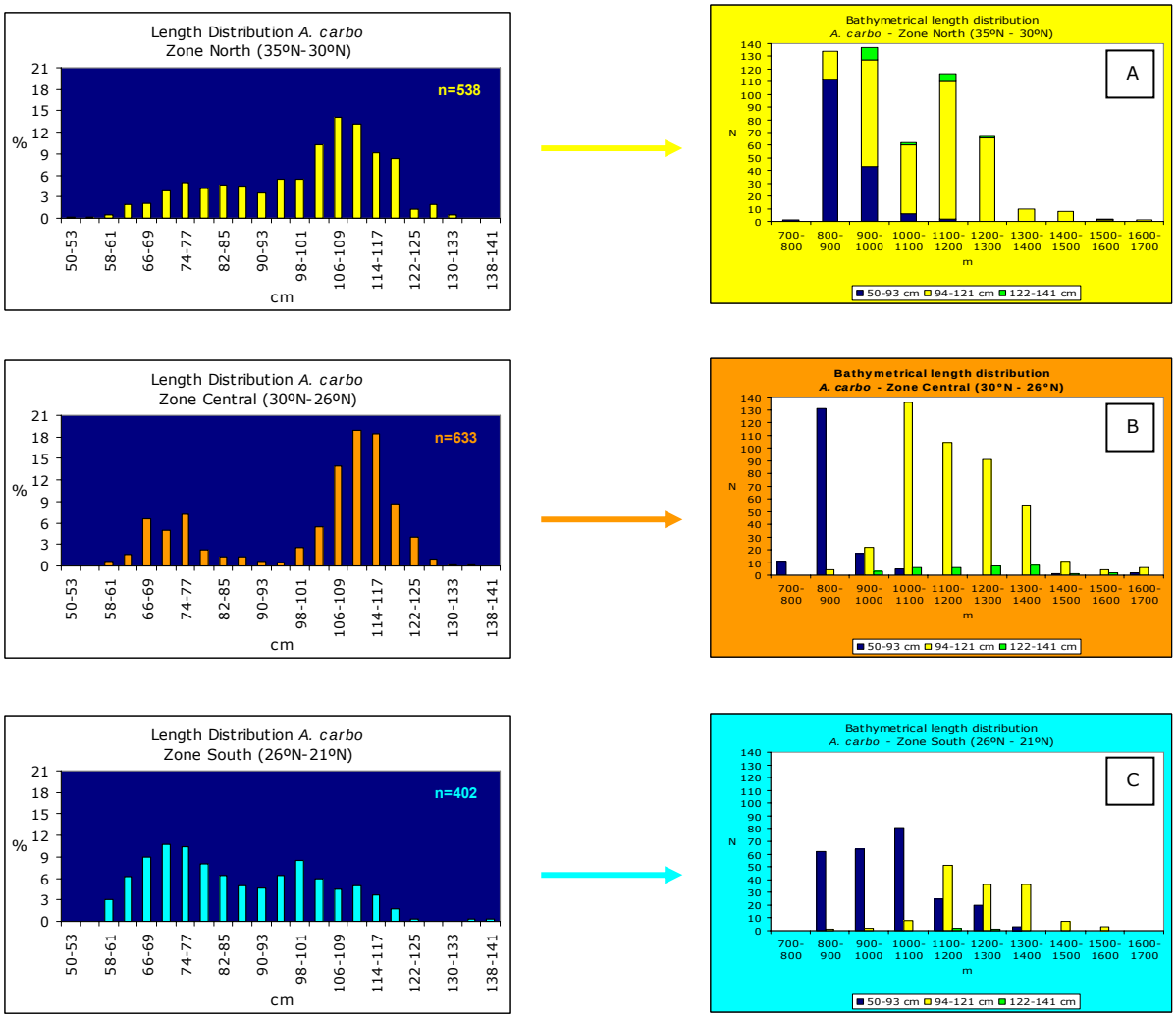

Figure 6.1.- Geographical and bathymetrical (A, B, C) length-frequency distribution of *A. carbo* from 35ºN to 21ºN

Results of the Kolmogorov-Smirnov test on the comparison of the same depth strata at the different Zones (North, Central and South) indicate the absence of statistical differences in the size structure of 900-1 000 m and 1 100-1 200 m strata between the North and Central Zones ($D_{max} < 0.2399$ and $D_{max} < 0.1814$, respectively). The size structure in the remaining depth strata were statistically different ($D_{max} > D_{0.05, (m,n)>25}$).

6.3.1.2. *Mean length evolution*

Results of mean length, standard deviation, length range and number of individuals used by sex, depth strata and latitude are shown in Table 6.4. For each geographical zone, mean length by depth and sex is presented (Figure 6.2).

Table 6.4.- Mean length, standard deviation (SD), length range and number of individuals (N) by sex, depth strata and latitude of *A. carbo*

		Zone North (35°N-30°N)				Zone Central (30°N-26°N)				Zone South (26°N-21°N)			
Depth (cm)	Sex	Mean length (cm)	SD (cm)	Length range (cm)	N	Mean length (cm)	SD (cm)	Length range (cm)	N	Mean length (cm)	SD (cm)	Length range (cm)	N
	Males	-	-	-	-	76.0	6.2	69-84	4	-	-	-	-
700-800	Females	-	-	-	-	80.0	6.4	71-86	5	-	-	-	-
	Indeterminates	61.0	-	61	1	73.0	1.4	72-74	2	-	-	-	-
	All individuals	61.0	-	61	1	77.3	6.0	69-86	11	-	-	-	-
	Males	81.6	13.3	63-111	19	76.7	10.9	66-107	18	67.5	7.7	59-102	36
800-900	Females	82.9	15.3	61-115	34	75.8	9.2	62-100	16	68.0	4.3	61-74	27
	Indeterminates	81.7	10.2	55-113	81	72.0	7.3	60-114	101	-	-	-	-
	All individuals	82.0	12.1	55-115	134	73.1	8.3	60-114	135	67.7	6.4	59-102	63
	Males	108.5	8.1	89-120	36	111.2	7.4	100-122	9	76.2	7.7	63-99	31
900-1000	Females	110.7	12.2	76-130	40	100.0	19.1	75-127	21	77.6	6.4	66-94	34
	Indeterminates	88.4	17.2	51-130	61	83.9	18.4	61-119	12	62.0	-	62	1
	All individuals	100.2	17.4	51-130	137	97.8	19.4	61-127	42	76.7	7.2	62-99	66
	Males	106.9	8.2	93-126	12	107.3	8.5	74-115	25	81.5	12.7	65-112	19
1000-1100	Females	110.6	8.2	101-131	14	110.0	8.1	87-122	41	84.7	13.3	62-117	20
	Indeterminates	100.6	8.8	66-113	36	110.6	7.2	66-124	81	73.8	7.7	60-96	50
	All individuals	104.1	9.5	66-131	62	109.9	7.7	66-124	147	77.9	11.3	60-117	89
	Males	110.5	5.1	102-120	33	113.1	4.3	107-122	19	97.3	15.8	64-124	29
1100-1200	Females	114.5	6.3	100-128	48	114.2	5.2	101-125	35	101.0	14.7	61-135	49
	Indeterminates	107.2	7.8	85-126	35	111.5	5.0	100-129	56	-	-	-	-
	All individuals	111.2	7.1	85-128	116	112.8	5.3	100-129	110	99.6	15.1	61-135	78
	Males	-	-	-	-	112.7	4.7	103-123	23	94.0	8.3	67-113	36
1200-1300	Females	-	-	-	-	115.5	6.1	106-135	27	102.7	13.1	72-139	20
	Indeterminates	110.7	6.5	97-122	67	113.0	5.3	100-123	48	120.0	-	120	1
	All individuals	110.7	6.5	97-122	67	113.6	5.5	100-135	98	97.5	11.3	67-139	57
	Males	110.5	7.8	105-116	2	110.9	5.0	101-118	16	97.9	6.7	93-111	8
1300-1400	Females	107.0	-	107	1	117.2	5.7	103-127	25	104.3	6.9	94-119	31
	Indeterminates	112.0	3.9	104-117	7	113.9	6.1	106-132	22	-	-	-	-
	All individuals	111.2	4.4	104-117	10	114.5	6.2	101-132	63	102.9	7.2	93-119	39
	Males	-	-	-	-	108.0	-	108	1	98.0	2.8	96-100	2
1400-1500	Females	-	-	-	-	-	-	-	-	107.2	4.7	103-114	5
	Indeterminates	112.8	7.3	96-120	8	109.6	11.3	81-123	12	-	-	-	-
	All individuals	112.8	7.3	96-120	8	109.5	10.8	81-123	13	104.6	6.0	96-114	7
	Males	-	-	-	-	-	-	-	-	-	-	-	-
1500-1600	Females	-	-	-	-	-	-	-	-	110.0	4.2	107-113	2
	Indeterminates	117.0	12.7	108-126	2	119.5	6.9	110-129	6	100.0	-	100	1
	All individuals	117.0	12.7	108-126	2	119.5	6.9	110-129	6	106.7	6.5	100-113	3
	Males	-	-	-	-	-	-	-	-	-	-	-	-
1600-1700	Females	-	-	-	-	118.0	1.4	73-114	2	-	-	-	-
	Indeterminates	109.0	-	109	1	98.5	17.5	117-120	6	-	-	-	-
	All individuals	109.0	-	109	1	103.4	17.3	73-120	8	-	-	-	-

Indeterminates: virgin and not determinate individuals were considered

North Zone

Males ranged from 63 to 126 cm while females ranged from 61 to 131 cm. If individuals are considered, then the range is from 51 to 131 cm. The widest length range was in the 900-1 000 m strata: 51-130 cm. Despite the small number of individuals sampled in some depth strata (700-800 and deeper than 1 300 m), there is a general trend to the increase of the mean length in relation to the depth: from 61 cm (700-800 m strata) to 117 cm (1 500-1 600 m strata) (Figure 6.2 A). Therefore, it seems that juveniles are more common lower than 900 m depth.

In relation to the distribution by sex and with the exception of the 1 300-1 400 m strata (probably due to small number of individuals sampled), the mean length of females was always higher than the males.

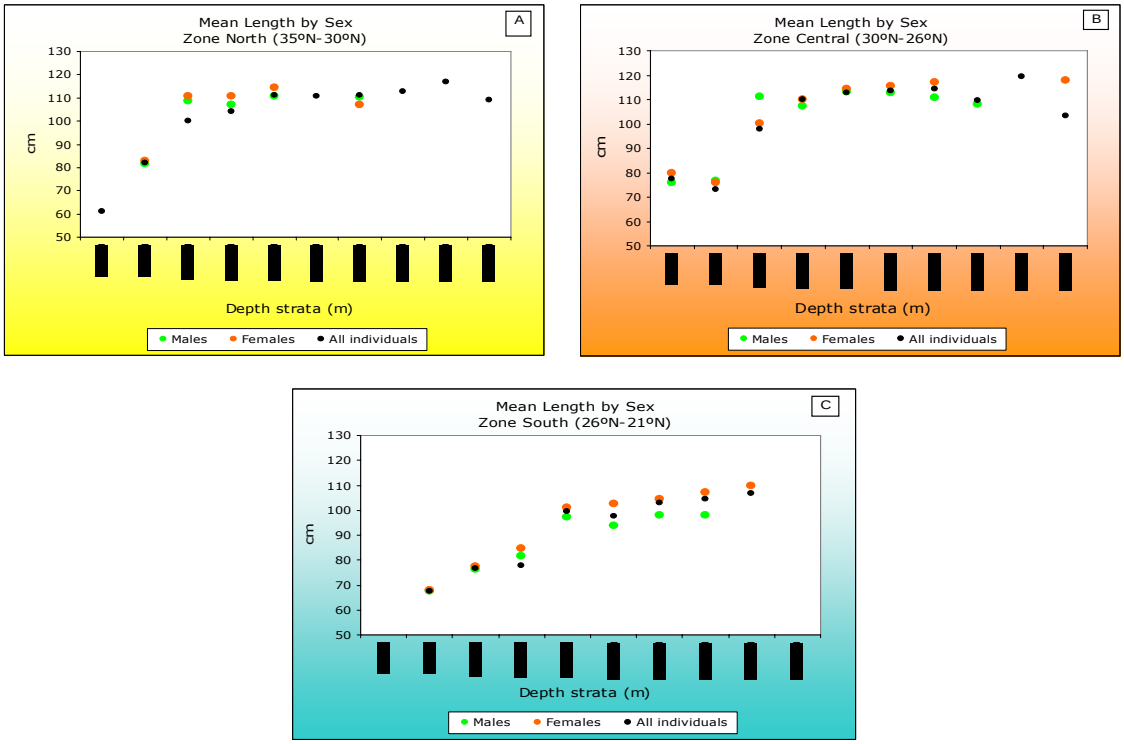

Figure 6.2.- Mean length evolution of *A. carbo* by depth strata and sex in the North (A), Central (B) and South (C) Zones

Central Zone

Males ranged from 66 to 123 cm while females ranged from 62 to 135 cm and, if all individuals are considered, then the range is from 60 to 135 cm. The minimum and maximum length range values in this area were higher than North Zone. As in the previous zone, the widest length range was in the 900-1 000 m strata: 61-127 cm. Once again, a general trend to the increase of the mean length in relation to the depth can be seen: from 73 cm (800-900 m strata) to 115 cm (1 300-1 400 m strata) (Figure 6.2 B). Juveniles are also more common lower than 900 m depth.

The mean length of females was also always higher than the males, except in the 800-900 m and 900-1 000 m.

South Zone

In this area males ranged from 59 to 124 cm and females from 61 to 139 cm. If all individuals are pooled together then the range is from 59 to 139 cm. The widest length range (61-135 cm) was obtained in the 1 100-1 200 m strata. Despite the small number of individuals sampled in some depth strata and as in

the north and central zones, a general trend in the increase of the mean length in relation to the depth is observed: from 68 cm (800-900 m strata) to 107 cm (1 500-1 600 m strata) (Figure 6.2 C). In this zone, juveniles are more common lower than 1 100 m depth.

6.3.2. *Sex ratio*

Males (♂) and females (♀) proportion in each study zone, taking into account all analyzed individuals was the following: North Zone (42.7% / 57.3%), Central Zone (40.1% / 59.9%) and South Zone (46.1% / 53.9%) (Figure 6.3). The number of females was always higher than males in the three zones: 1♂:1.34♀, 1♂:1.50♀ and 1♂:1.17♀.

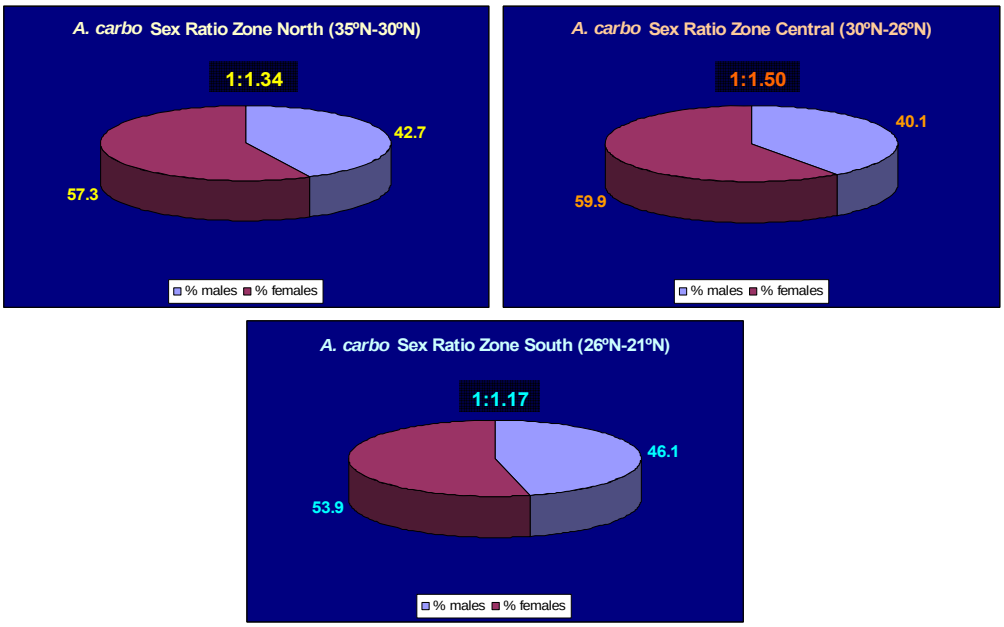

Figure 6.3.- Total sex ratio of *A. carbo* by geographical area

In order to detect a possible sex segregation by depth strata and/or latitude, a sex-structure analysis was carried out on 10 cm size class, from 800 to 1 300 m depth (the most representative depth strata) by area (North, Central and South Zones) (Table 6.5).

Table 6.5.- Sex ratio by area, size class and depth (M: males; F: females; X^2 analysis[a])

Zone North (35°N-30°N)

Size class	800-900 m				900-1000 m				1000-1100 m				1100-1200 m				1200-1300 m				Total			
(cm)	M	F	Sex ratio	X^2	M	F	Sex ratio	X^2	M	F	Sex ratio	X^2	M	F	Sex ratio	X^2	M	F	Sex ratio	X^2	M	F	Sex ratio	X^2
50-60																								
61-70	3	9	1:3.00	3.00																	3	9	1:3.00	3.00
71-80	10	9	1:0.90	0.05		1															10	10	1:1.00	
81-90	1	5	1:5.00	2.67	1	2	1:2.00	0.33													2	7	1:3.50	2.78
91-100	2	6	1:3.00	2.00	5	4	1:0.80	0.11	1					1							8	11	1:1.38	0.47
101-110	2	3	1:1.50	0.20	13	13	1:1.00		9	7	1:0.78	0.25	18	11	1:0.61	1.69					42	34	1:0.81	0.84
111-120	1	2	1:2.00	0.33	17	10	1:0.59	1.81	1	6	1:6.00	3.57	15	28	1:1.87	3.93					34	46	1:1.35	1.80
121-130						10			1					8							1	18	1:18.00	15.21
131-140										1												1		
Total	**19**	**34**	**1:1.79**	**4.25**	**36**	**40**	**1:1.11**	**0.21**	**12**	**14**	**1:1.17**	**0.15**	**33**	**48**	**1:1.45**	**2.78**					**100**	**136**	**1:1.36**	**5.49**

Zone Central (30°N-26°N)

Size class	800-900 m				900-1000 m				1000-1100 m				1100-1200 m				1200-1300 m				Total			
(cm)	M	F	Sex ratio	X^2	M	F	Sex ratio	X^2	M	F	Sex ratio	X^2	M	F	Sex ratio	X^2	M	F	Sex ratio	X^2	M	F	Sex ratio	X^2
50-60																								
61-70	6	5	1:0.83	0.09																	6	5	1:0.83	0.09
71-80	9	6	1:0.67	0.60		6			1												10	12	1:1.20	0.18
81-90	1	4	1:4.00	1.80		2				2											1	8	1:8.00	5.44
91-100	1	1	1:1.00		1				2	3	1:1.50	0.20									4	4	1:1.00	
101-110	1				3	5	1:1.67	0.50	11	15	1:1.36	0.62	6	9	1:1.50	0.60	6	4	1:0.67	0.40	21	33	1:1.57	2.67
111-120					4	6	1:1.50	0.40	11	19	1:1.73	2.13	12	21	1:1.75	2.45	16	18	1:1.13	0.12	33	64	1:1.94	9.91
121-130					1	2	1:2.00	0.33		2			1	5	1:5.00	2.67	1	4	1:4.00	1.80	18	13	1:0.72	0.81
131-140																		1			1	1	1:1.00	
Total	**18**	**16**	**1:0.89**	**0.12**	**9**	**21**	**1:2.33**	**4.80**	**25**	**41**	**1:1.64**	**3.88**	**19**	**35**	**1:1.84**	**4.74**	**23**	**27**	**1:1.17**	**0.32**	**94**	**140**	**1:1.49**	**9.04**

Zone South (26°N-21°N)

Size class	800-900 m				900-1000 m				1000-1100 m				1100-1200 m				1200-1300 m				Total			
(cm)	M	F	Sex ratio	X^2	M	F	Sex ratio	X^2	M	F	Sex ratio	X^2	M	F	Sex ratio	X^2	M	F	Sex ratio	X^2	M	F	Sex ratio	X^2
50-60	6																				6			
61-70	21	18	1:0.86	0.23	7	5	1:0.71	0.33	1	1	1:1.00		2	1	1:0.50	0.33	1				32	25	1:0.78	0.86
71-80	8	9	1:1.13	0.06	16	18	1:1.13	0.12	12	5	1:0.42	2.88	3	2	1:0.67	0.20	1	1	1:1.00		40	35	1:0.88	0.33
81-90					6	10	1:1.67	1.00	3	10	1:3.33	3.77	2	11	1:5.50	6.23	7	2	1:0.29	2.78	18	33	1:1.83	4.41
91-100					2	1	1:0.50	0.33		2			8	9	1:1.13	0.06	22	4	1:0.18	12.46	32	16	1:0.50	5.33
101-110	1								2				9	8	1:0.89	0.06	4	9	1:2.25	1.92	16	17	1:1.06	0.03
111-120									1	2	1:2.00	0.33	4	15	1:3.75	6.37	1	3	1:3.00	1.00	6	20	1:3.33	7.54
121-130													1	2	1:2.00	0.33					1	2	1:2.00	0.33
131-140														1				1				2		
Total	**36**	**27**	**1:0.75**	**1.29**	**31**	**34**	**1:1.10**	**0.14**	**19**	**20**	**1:1.05**	**0.03**	**29**	**49**	**1:1.69**	**5.13**	**36**	**20**	**1:0.56**	**4.57**	**151**	**150**	**1:0.99**	**0.00**

[a] $X^2 > X^2_{t1,\ 0.05} = 3.841$

The sex ratio in the North and Central Zones (1:1.36 and 1:1.49, respectively) shows a statistically significant predominance of females. However, in the South Zone this value was practically equal to 1 (1:0.99).

In the **North Zone**, the number of males and females differ with the depth strata. If there are some depth strata where sex ratio was similar to 1 (900-1 000 m and 1 000-1 100 m), other depth strata (800-900 m and 1 100-1 200) presented a sex ratio in favour of females. However, neither relationship differs statistically from 1:1.

In the **Central Zone**, like in the North Zone, the number of females was usually higher than males with the exception of 800-900 m strata where the number of males was higher. Particularly, in the 900 to 1 200 m strata the number of females was significantly greater than males (χ^2 –test, $p<0.05$).

In the **South Zone** the number of females was also higher than males (except in 800-900 m and 1 200-1 300 m depth strata) but the number of females was only significantly greater than males (χ^2 –test, $p<0.05$) in the 1 100-1 200 m strata.

In the North Zone females were more abundant, with differences statistically significant between 800-900 m, in the Central Zone between 900-1 200 m and between 1 100-1 200 m in the South Zone. The number of females increased progressively with depth from north to south, being more significantly in the Central Zone (Figure 6.4).

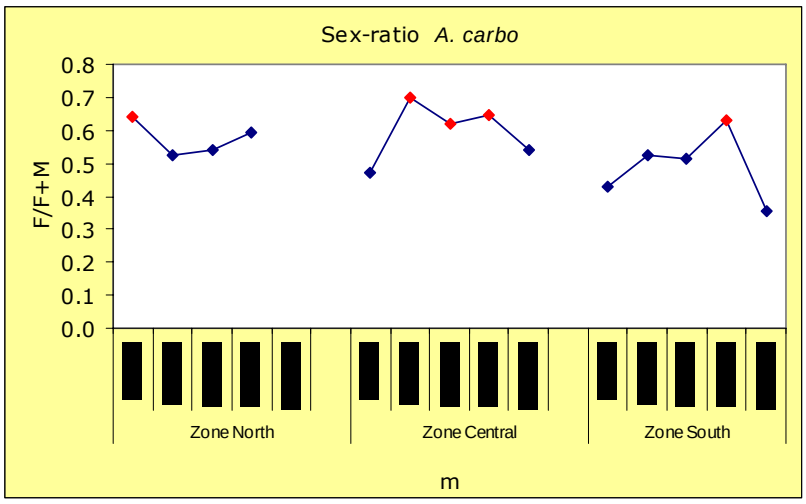

Figure 6.4.- Sex ratio by depth and zone of *Aphanopus carbo*

Males and females proportion analysis by size range in each fishing zone showed that from 100-110 cm, females' proportion increases considerably in relation to the males (Figure 6.5). Only in the Zone South, where the smallest individuals are more abundant, below 80 cm total length, the percentage of males was higher than the percentage of females.

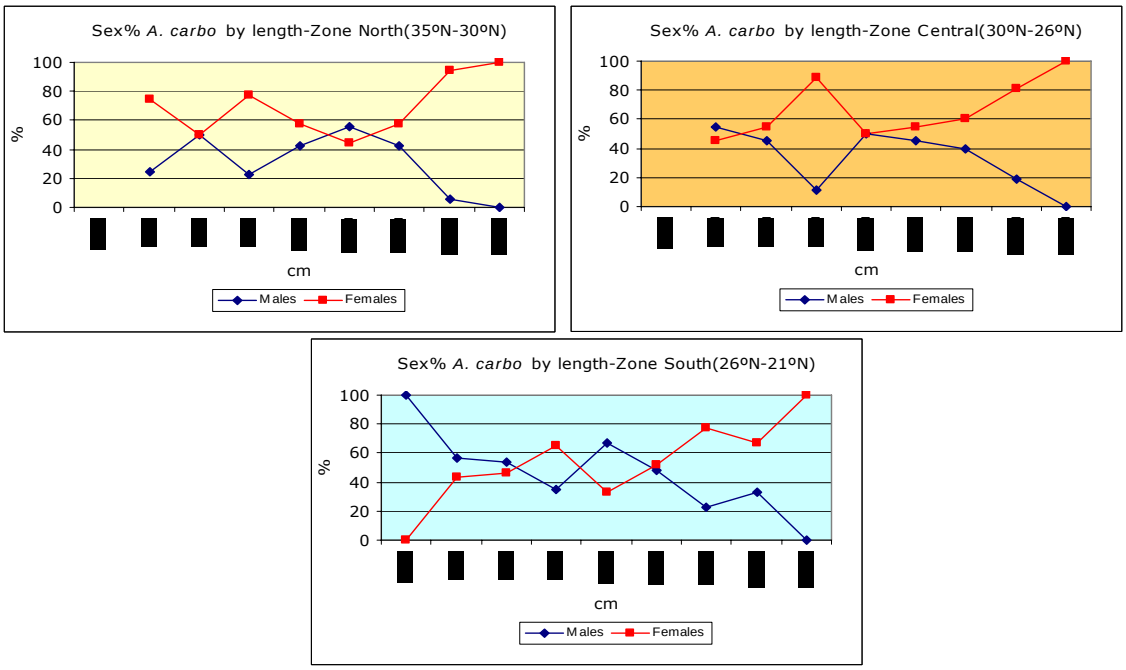

Figure 6.5.- Sex proportion by length range of *A. carbo* by geographical zone

6.4. Discussion

The smallest individual (51 cm) was captured in the North Zone and the largest one (139 cm) in the South Zone. This length range is less extend than the one found by Morales-Nin & Sena-Carvalho (1996), off Madeira (54 and 151 cm), but wider than the one registered by Martins *et al*. (1989) for the Portuguese continental fishery (72-134 cm) and includes more range group than another one registered by Pajuelo *et al.* (2008) in waters off Canary Islands (100-148 cm).

Bordalo-Machado *et al.* (2001), in a study on the length composition from NW Scotland, Sesimbra (Portugal Mainland) and Funchal (Madeira) concluded that *A. carbo* length range varies between areas. Specimens with the largest total length were found in Funchal (above 140 cm) whereas the smallest size was recorded in the NW Scotland (below 65 cm). Thus, large individuals were more frequent at southern areas than at the northern ones. This difference on length distributions between northern and southern areas (separated by parallel 40ºN) was also observed on a recent study based on an enlarged length dataset in the Northern Atlantic Ocean (Carvalho & Figuereido, 2001). One hypothesis to explain this behaviour can be that the areas north of 40ºN are probably sectors to where the species migrates in search of food during its first years of life, whereas the reproduction and feeding of adults individuals happen in the waters of the Macaronesian archipelagos (Morales-Nin *et al.*, 2002; Figueiredo *et al.*, 2003).

This same conclusion was attained by Swan *et al.* (2003) which found that in Trawl Fishery from Rockall Trough (west of UK and the Irish continental shelf) individuals were smaller (80-100 cm) than those from Sesimbra (86-125 cm). However recent Spanish landings from Hatton Bank (Anon., 2000b, *in* Swan *et* al., 2003) do not confirm this hypothesis since the sampled fish had a length range from 80 to 120 cm.

According to Magnusson *et al.* (2000), in Icelandic waters the overall length ranged from 56 to 125 cm. Females were larger than males, the mean lengths being 100.30 cm and 93.27 cm, respectively. The majority of females were 90 to 110 cm while males were 85 to 105 cm. In waters off the Canaries, a higher maximum size for females than for males was found. Males' size range varied

between 104 to 134 cm, and females´ between 100 and 148 cm (Pajuelo *et al.*, 2008).

In our study, the comparisons between mean length obtained in each depth strata for both males and females showed that there are no significant differences between them (two-way ANOVA, p= 0.1745). However, an extremely significant effect related to the depth was found ($p < 0.0001$).

Moreover, our results indicate that, between 35ºN and 21ºN, there is an increase of the size with depth, which means that a bathymetrical segregation by size may occur. In fact, the smallest individuals (53-94 cm) were located in the lower depth strata (mainly until 1 000 m), and the largest were caught in depths greater than 1 200 m. Concerning the geographical distribution, there was an increase in number of the smallest size individuals in the South Zone (26ºN-21ºN) in relation to the Central (30ºN-26ºN) and the North (35ºN-30ºN) Zones. In addition, the South zone presented the widest bathymetrical distribution of small size individuals (within a depth range of 900-1 400 m) and their highest abundance: 256 small size exemplars from a total of 402 individuals (more than 50%).

Females were more numerous than males (458 females *vs.* 396 males) and although no significant statistical differences were found, the mean length of females was higher than the males. This was also found by Magnusson *et al*., 2000 (*in* Swan *et al*., 2003) in the Iceland slope and Reykjanes Ridge (south of Iceland), where most of females presented sizes between 90 and 110 cm and males between 85 and 105 cm. However, it's important to emphasize that our study is based on samples obtained during November-December and we don't know what could happen during the rest of the year (fishery incorporation of the smallest individuals, possible aggregation according to the spawning period, etc).

According to BASBLACK Final Report (Anon., 2000a) in Madeira the analysis of sex ratio by length class showed a dominance of males smaller than 110 cm total length, while females predominated at larger sizes. In Sesimbra (Portugal Mainland), both sexes presented the same trend. In Hatton Bank males were more abundant than females up to 102 cm and above this size; females were

more abundant, increasing the percentage quickly to reach 100%. In the ICES Area X (Azores) males displayed a sex ratio higher than females up to 120 cm and above 124 cm all individuals were females. According to Bordalo-Machado *et al*. (2001) females were more abundant in north than in the south of Madeira. In Canary Islands waters, proportion of males (135) to females (233) differs significantly from the 1:1 ratio, being clearly unbalanced in favour of females (1:1.72). In sizes larger than 123 cm, females were considerably more abundant than males (Pajuelo *et al.*, 2008).

Comparing the sex ratio with depth, females were more abundant than males by strata and studied areas, except between 800-900 m in the Central and South Zones, and between 1 200-1 300 m in the Zone South. The results obtained by Morales-Nin & Sena-Carvalho (1996) in Madeira waters showed that the females also dominated monthly captures. However, Sena-Carvalho (1988) founded sex ratio near 50% during spawn period in October-November. Pajuelo *et al.* (2008) in Canary Islands found that males and females were distributed throughout all the layers under study, but without existence of segregation by depth.

Sex ratio analysis by size range and depth strata indicated non determined pattern neither in same latitude nor in same strata at different latitudes. Nevertheless, in relation to depth it seems that *A. carbo* displays segregation by sex in direction north-south (from 35ºN-21ºN).

7. MATURITY

7.1. Introduction

In this chapter, maturity stages by sex and area are studied. Although we don't have monthly information that allows the determination of the spawning period, a summary of the available information in relation with the length of first maturity and spawning period as well as a comparison with our results are also presented.

7.2. Material and Methods

In this study we used the maturity scale developed for the black scabbardfish by Gordo *et al*. (2000). This scale has five differentiated maturity stages for both sexes: I: Immature, II: Developing, III: Pre-spawning, IV: Spawning and V: Post-spawning.

A total of 854 individuals of *A. carbo*: 241 in North Zone, 347 in Central Zone and 266 in South Zone were analyzed.

7.3. Results

Percentage of each maturity stage by sex and area is presented in Figure 7.1:

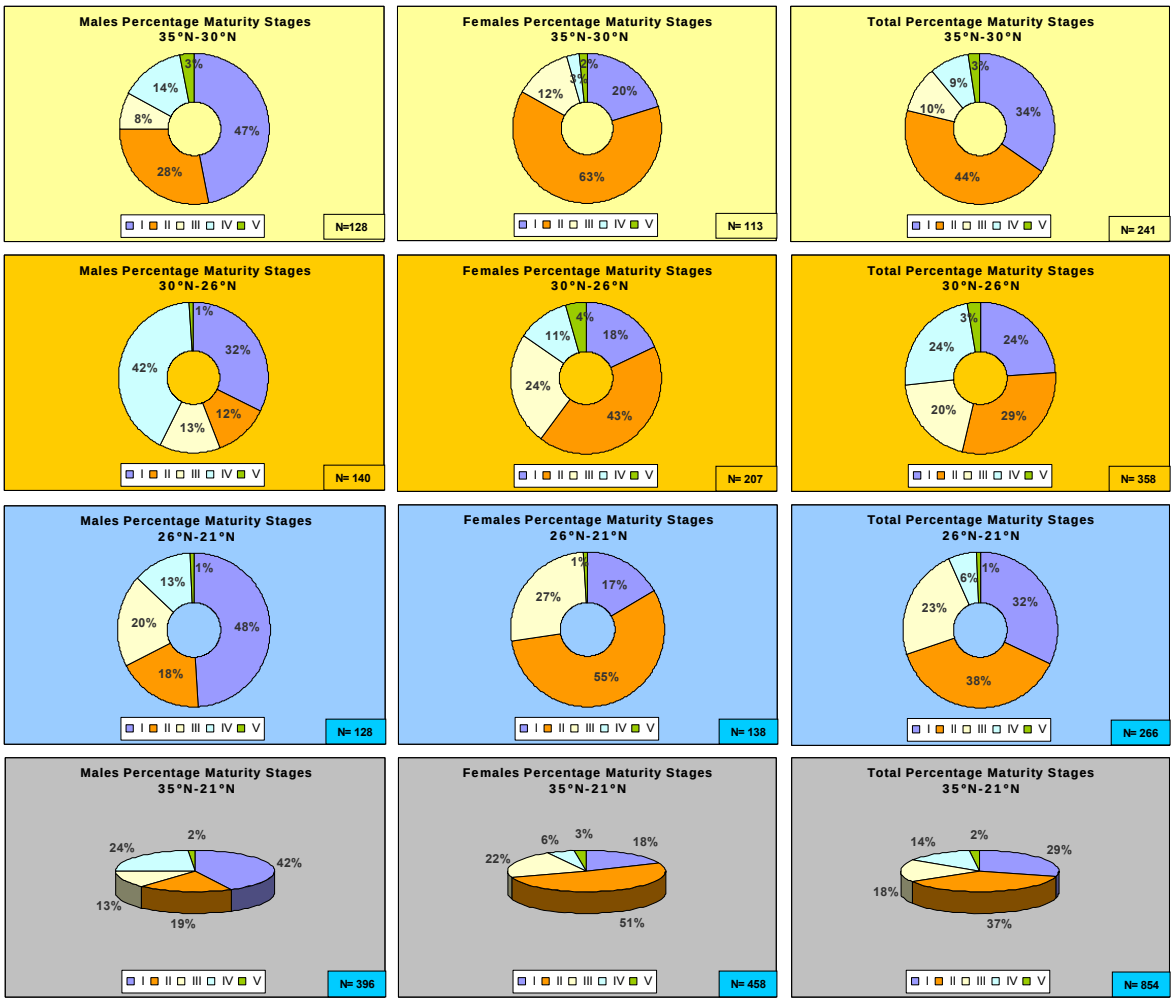

Figure 7.1.- Percentage of maturity stages by sex and area

In **North Zone** (35ºN-30ºN), it can be seen that the highest percentage of males (47%) corresponded to stage I, followed by stage II and IV (28 and 14%, respectively). In the other hand, the highest percentage of females (63%) corresponded to stage II, followed by stage I (20%) and stage III (12%). In both sexes, stage V was the worst represented, with values around 3%.

In **Central Zone** (30ºN-26ºN), the highest percentage of males was recorded in stage IV (42%), followed by stage I (32%) and stage III (13%). Regarding females, stage II (43%), stage III (24%) and stage I (18%) were the stages with the highest percentages.

In **South Zone** (26ºN-21ºN), the highest percentage of males was recorded in stage I (48%), followed by stage III (20%) and II (18%). Regarding females, the highest percentage was recorded in stage II (55%), followed by stage III

(27%) and I (17%). It is important to emphasize that, in this zone, no female in stage IV was found.

A spatial analysis of the data shows that North and South zones present the same trend in both males and females, with a higher percentage of immature males and developing females and almost no representation of spawning individuals, especially females. On the contrary, Central zone is characterised by presenting a higher percentage of spawning individuals, especially males, in comparison with the other two zones.

A maturity stage distribution by the most representative depth strata (800-1 300 m), was also made by sex and zone. It was observed that different maturity stages were distributed in an irregular way, although highest percentages were found in expected strata. It means that, as length increase with depth (Chapter 6), it was expected that initial stages were more represented in less depth and developed/ spawning stages in deeper zones. This fact was more evident in South Zone where a higher percentage of smaller individuals exist (Chapter 6).

Thus, as it can be seen in Figure 7.2, highest percentages for stage I was found between 800-1 000 m in North and Central Zones, where it diminished progressively with depth. Regarding stage IV, spawning individuals are distributed in an irregular way, with very small or null percentages between 800-1 100 m in North and South Zones while in Central Zone individuals presents an increase with depth. Lastly, in all zones, spawning individuals reaches its highest percentages at 1 200-1 300 m.

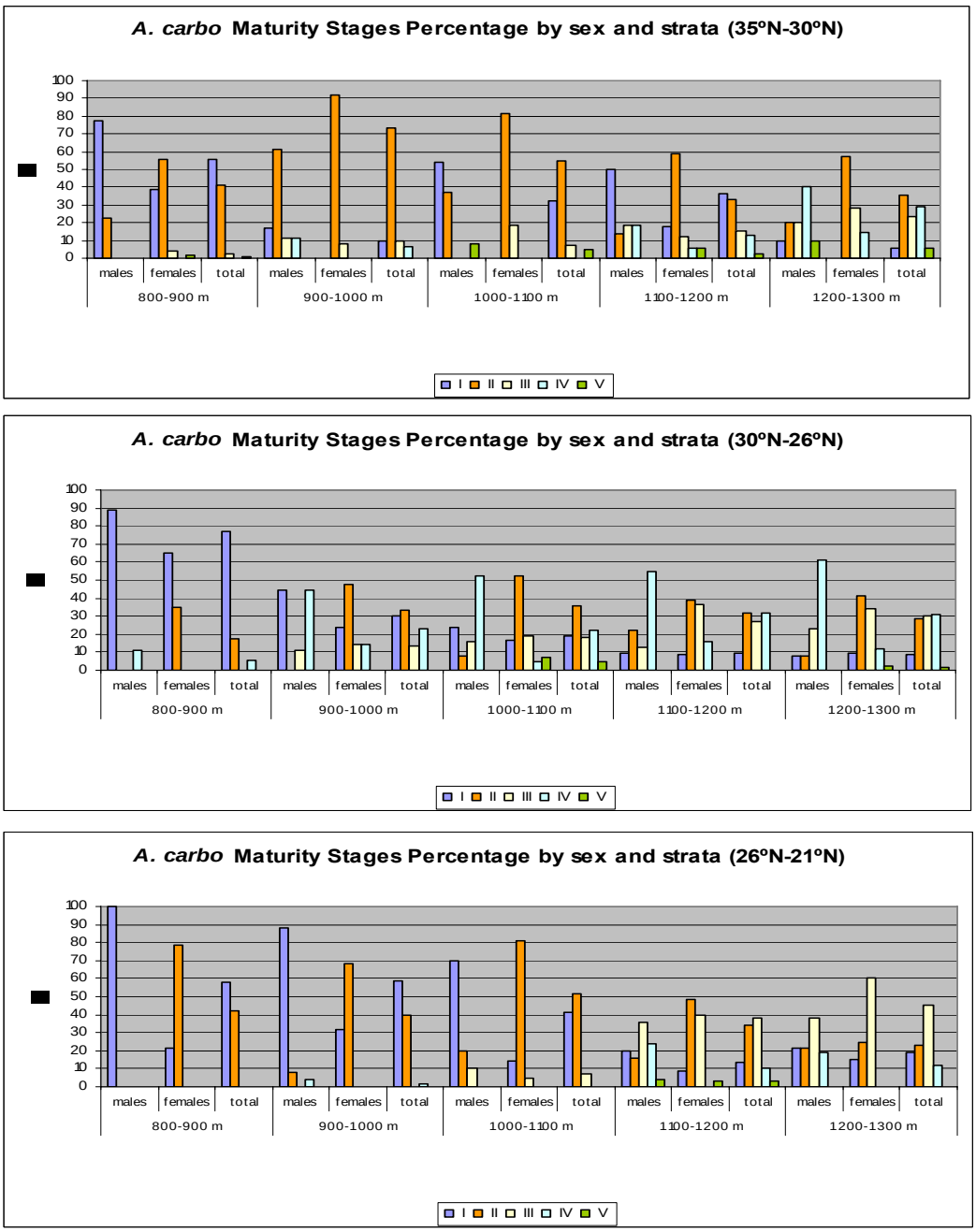

Figure 7.2.- *A. carbo* maturity stages by sex and strata in North, Central and South Zones

In addition, a summary of the maturity information obtained by other authors for this species in different geographical areas is presented (Tables 7.1 and 7.2).

Table 7.1.- Length at first maturity according to other authors

AREA	LENGTH AT FIRST MATURITY		AUTHOR
	♂	♀	
Madeira	74 cm	103 cm	Sena-Carvalho *et al.* (*in prep., in* Anon. 2000b)
	—	103 cm	Bordalo Machado *et al.* (2001). Figueiredo *et al. (* 2003)
Canary Islands	110 cm	115 cm	Pajuelo *et al.* (2008)
South of NE Atlantic	109 cm	115 cm	Carvalho (2001)
North Atlantic	80-85 cm		Zilanov & Shepel (1975). Nakamura & Parin (1993)
Hatton Bank (NE Atlantic)	91 cm	85 cm	Anon. (1999b)
Iceland	84-88 cm	92-97 cm	Magnusson *et al. (* 2000)

Table 7.2.- Spawning period by area according to other authors

AREA	SPAWNING PERIOD		AUTHOR
	♂	♀	
Madeira	August-December	September-December	Anon. (2000a), Bordalo-Machado *et al.* (2001), Figueiredo *et al. (* 2003)
	August-December	October-December	Sena-Carvalho (1988) *in* Morales-Nin & Sena-Carvalho (1996), Carvalho (2001)
Azores	November- April		Vinnichenko (2002) *in* Quinta *et al*. (2004)
Canary Islands	July-December		Pajuelo *et al.* (2008)
NE Atlantic	November- April		Zilanov & Shepel (1975)
West of Brithish Iles	November- April		Nakamura & Parin (1993)
Icelandic waters	January-March		Magnusson & Magnusson (1995), Magnusson *et al*. (2000)

7.4. Discussion

Regarding length at first maturity, in all cases except in Hatton Bank (NE Atlantic), this length was smaller in males than in females, which indicates that males reach the first maturity before females. Differences in size-at-sexual-maturity in divergent geographical areas could be related to differences in regional oceanographic conditions, in stock's biology, in sample size and/or their level of exploitation (Morales-Nin *et al.*, 2002).

In relation to the spawning period, for the three years of study, percentage of spawning individuals (stage IV) was always superior in males. On the other hand, in our study area, females presented always a higher percentage of pre-spawning individuals than males. This could indicate an advance of the males in relation to females in spawning period. This same fact was observed in Madeira, where information on both sexes is available: males begin spawning in August and females in September.

Due to the seasonality of our samples, collected exclusively during November-December; it is impossible to determine a precise spawning period as well as a length at first maturity or massive maturity. However, the high percentages of males and females in stage II and III-IV, and the low percentages of individuals in stage V founded in this study (November) seem to indicate that individuals were preparing to spawn probably in the beginning of December.

According to Bordalo-Machado *et al*. (2001) and Figueiredo *et al.* (2003) two distinct reproductive strategies seem to occur in Madeira: smaller size individuals spawn between September and December while larger individuals preferentially undertake spawning in January and February.

According to Vinnichenko (2002), Zilanov & Shepel (1975) and Nakamura & Parin (1993), spawning individuals were encountered in Azores, Northeastern Atlantic and West of British Isles, respectively, from November to April. Within this same period, Magnusson & Magnusson (1995) and Magnusson *et al.* (2000) found spawning individuals in Icelandic waters, from the beginning of January until March. This situation seems to be more adjusted to what happens in our study area, although our data must be seen as preliminary due to the lack of annual cycle information.

According to the available information, spawning period does not seem to follow a determinate pattern. On contrary, spawning period differs between geographical areas: in Madeira, spawning period last from August to December, in Icelandic waters last from January to March and surprisingly, West of British Isles, Azores and NE Atlantic shares the same spawning period (November-April). According to all these authors, it would be logical to say that black scabbardfish exhibits temporal sexual maturation differences according to different areas in NE Atlantic.

On the other hand, several authors have shown the existence of horizontal migrations to spawning and nursery grounds for this species (Kelly *et al.*, 1998, Figueiredo *et al.*, 2003). All these evidences indicate that this species is distributed in the N Atlantic both in continental and insular waters, but probably

moves away to oceanic waters close to the Atlantic Islands in search of food and in order to spawn (Pajuelo *et al.*, 2008).

In the case of *A. carbo* in the NW Africa, it would be necessary to complete this study with monthly information on maturity, and thus, be able to explain the duration of the spawning in this area.

8. LENGHT-WEIGHT RELATIONSHIP

8.1. Introduction

Length and weight of a fish allow increasing the knowledge on the structure of a population, since these variables reflect the interactions of the reproduction, growth and mortality rates of the individuals. Also, they constitute a base for growth determination (Lorenzo, 1992).

On the other hand, this relationship can also be used as a condition index for fish inhabiting a certain geographical area (Petrakis & Stergiou, 1995).

8.2. Material and Methods

The equation $W=aL^b$ (Ricker, 1975) was used to estimate the length-weight relationship separately for males and females where W= body weight (g), L = total length (mm) and *a* and *b* are constants.

A total of 874 individuals of *Aphanopus carbo* were analyzed: 251 from North Zone, 358 from Central Zone and 265 from South Zone.

Slopes and intercepts for both males and females were compared using an ANCOVA test through the GraphPad Prism version 4.00 for Windows.

A summary of length-weight relationship from other geographical areas will be also presented.

8.3. Results

First of all, it is important to clarify that our study only represents a population's fraction and therefore the results must be used with great cautious.

Length-weight relationship, calculated by sex and both sexes combined in each study area, is shown in Table 8.1, and their graphical representation in Figure 8.1.

Table 8.1.- Length-weight relationship by sex and study area

Area	Sex	a	b	r²	N	Size range (cm)
35°N-30°N	Males	3. 1617E-07	3. 1965	0.96	128	51-126
	Females	2. 5679E-07	3. 2292	0.98	113	61-132
	Total	3. 2126E-07	3. 1955	0.97	251	51-132
30°N-26°N	Males	5. 6695E-07	3. 1216	0.98	140	62-129
	Females	4. 5091E-07	3. 1543	0.98	207	62-135
	Total	4. 5181E-07	3. 1541	0.97	358	62-135
26°N-21°N	Males	2. 0281E-07	3. 2714	0.98	127	60-125
	Females	2. 2571E-07	3. 2552	0.98	126	61-140
	Total	2. 1817E-07	3. 2602	0.98	265	60-140

Regarding *b* values, it is observed that all results are superior to the prospective value 3. A t-student test showed that *b* values were statistically different from 3 ($P<0.0001$) which indicates a positive allometry. By zone, lower *b* value appears in Central Zone followed by North Zone and South Zone. By sex, females present higher values than males except in South Zone.

R^2 values (close to 1) indicate that data for 51-140 cm size range were quite well adjusted. The highest value by sex and total corresponded to South Zone (0.98).

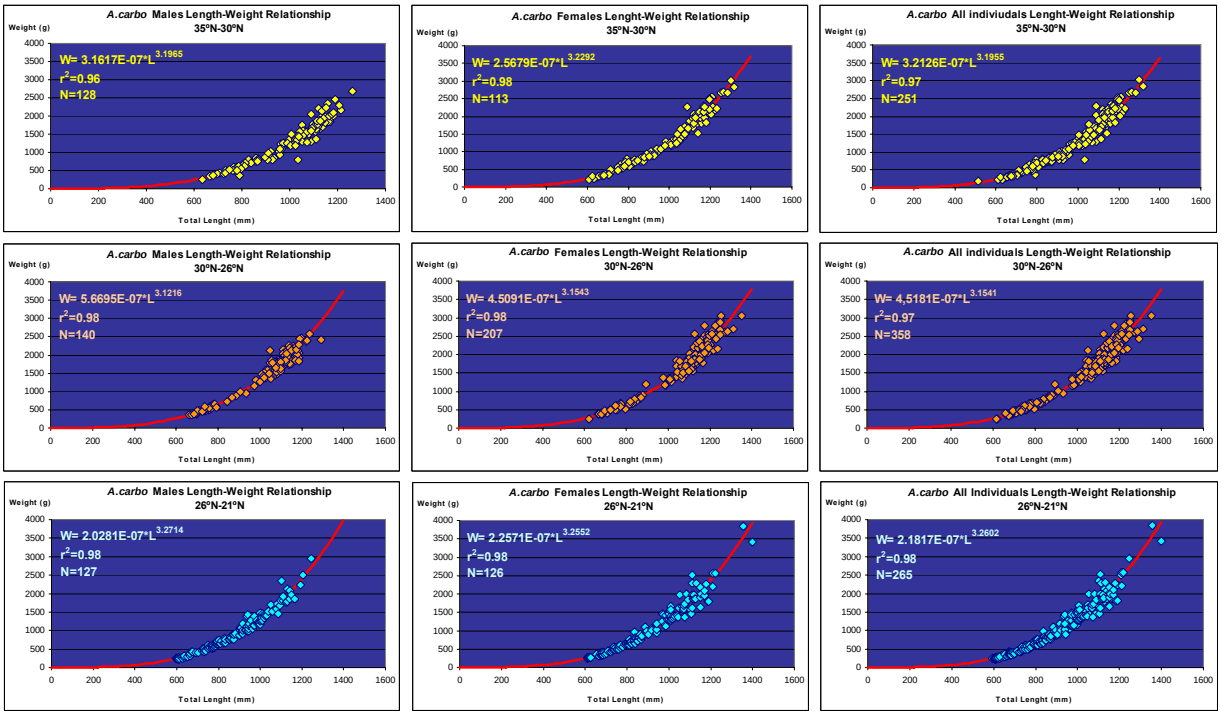

Figure 8.1.- Length-weight relationship by sex and study area

These graphs represent the real dispersion of our data in relation to a theorical curve (in red). It can be seen that all zones are quite adjusted to the theorical curve, even by sex. Females reach, in all the study area, higher weight and length values than males. These results were already expected since, in Chapter

6, we have observed that females reach larger sizes than males and it is known the closer relationship between these two parameters.

Statistical analysis between males and females length-weight relationship by area (ANCOVA: ($P<0.0001$)) showed that the differences between sexes for all study zones were extremely significant.

Table 8.2 presents a summary of the length-weight relationships found for other geographical areas.

Table 8.2.- Length-weight relationship by geographical area according to other authors

L-W Relationship	Males					Females					Totals					Author
Area	a	b	r^2	N	Size range (cm)	a	b	r^2	N	Size range (cm)	a	b	r^2	N	Size range (cm)	
Madeira	0.000154	3.45	0.95			0.000201	3.39	0.95								Morales-Nin & Sena-Carvalho (1996)
Portuguese coast (Sesimbra)											0.000376	3.27	0.70	1042	66-132	Martins *et al.* (1989), Anon. (1995)
Mid-Atlatinc Ridge (N Azores-Reikjanes Ridge)	0.0001	3.50	0.98	117	67-117	0.0001	3.55	0.98	131	60-139	0.0001	3.53	0.98	248	60-139	Duran Muñoz & Román (2000) *in* Anon (2000b)
Icelandic slope and Reikjanes Ridge	0.0000675	3.66	0.79			0.0001501	3.49	0.67								Magnusson & Magnusson (1995), Anon. (1995)
Icelandic waters	0.0001	3.61	0.92			0.0001	3.65	0.86			0.0001	3.63	0.90			Magnusson *et al.* (2000)
Hatton Bank in 1997	0.00051	3.21	0.84	65	81-110	0.00006	3.67	0.91	72	77-114						Anon. (1999a)
Hatton Bank in 1999	0.00006	3.69	0.95	168	71-117	0.0000553	3.69	0.94	81	72-117						Anon. (1999b)
Rockall Trough											0.0001	3.62		88		Anon. (1995)
Hebrides Terrace (NE Atlantic)											0.0000597	3.68			69-120	Lorance, *pers.comm in* Anon (2000b)

8.4. Discussion

Value of the parameter *b* in the length-weight relationship characterizes an isometric growth when equal to 3 (Ricker, 1975). In the present study these values for *A. carbo* showed a positive allometry in the growth of males and females. The positive allometry means that black scabbardfish weight increase is proportionally higher than length increase.

According to the available information, the estimated parameters of length-weight relationships seem to differ among geographical areas. This difference could be due to different physiological and environmental conditions that vary with geographical locations.

It is observed that in the northern areas of Atlantic Ocean (Iceland, Rockall Trough, Hatton Bank and Hebrides Terrace), values are almost always superior to 3.60 (Magnusson & Magnusson, 1995; Magnusson *et al.*, 2000; Anon., 1995;

Anon., 1999a, Anon., 1999b and Anon., 2000b). In mid-latitudes (Sesimbra, Portugal Mainland) values are nearer to ours (3.27) (Martins *et al*., 1989 and Anon. 1995), while in Madeira, *b* value seems to be independent from the other regions (3.3906 for females and 3.4519 for males (Morales-Nin & Sena-Carvalho, 1996)). Females present higher *b* values than males except in Madeira and Icelandic waters (Icelandic Slope and Reykjanes Ridge).

The number of individuals (N) analyzed in other geographical areas is not very ample in comparison with our study area (874 individuals), except in Sesimbra were 1 042 individuals were analyzed.

In conclusion, length-weight relationship for black scabbardfish in all geographical areas indicated a positive allometry in the growth. However, this relationship differs between North-East and Central Atlantic Ocean, and does not seem to follow a geographical pattern.

9. AGE AND GROWTH

9.1. Introduction

Age determination and growth studies are fundamental steps for the understanding of the biology of the species and for its appropriate management. In fact, growth parameters and others obtained from the age studies (mortality, selectivity, etc.) are included in most population dynamics models used in fisheries research. Age and growth data also allow determining changes in the population caused by the rates of exploitation (Morales-Nin, 1991).

Growth can be determinate by one or several methods (Morales-Nin, 1991):

- Anatomic method: enumeration of growth rhythmic marks in hard tissues.
- Length frequency analysis: progression of identifiable modes in size classes along time.
- Direct estimation: direct mensurations of growth rate of some exemplars and extrapolation to the population.

In this work, growth parameters estimation was made following the anatomic method, concretely, from otoliths analysis. Otoliths are calcareous structures that are in two adjacent cavities of the neuro-skull: otics capsules. There are three pairs of otoliths: *sagitta* (sacullus), *lapillus* (utriculus) and *asteriscus* (lagena). S*agitta* is the most used in age determination studies and is related with audition (Leta & Kleim, 1982).

A. carbo sagitta otoliths are oblongs and shows growth zones around a central zone. Different parts of *Aphanopus carbo sagitta* otolith can be seen in Figure 9.1:

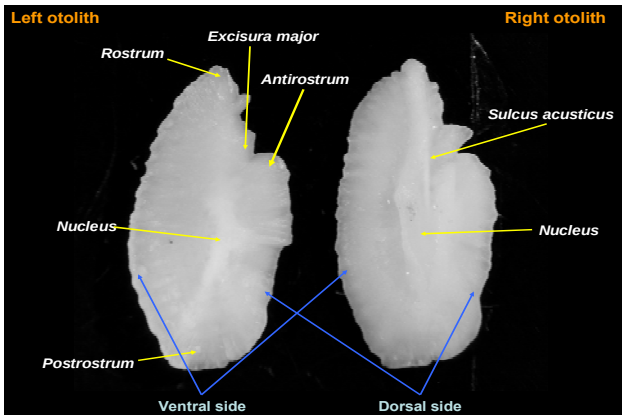

Figure 9.1.- General description of *Aphanopus carbo sagitta* otolith

In this chapter, some allometric relationships and growth parameters, by sex, estimated from length-age pairs of values and from mean-length by age-class (from the correspondents' length–age keys), will be presented. Possible growth differences by sex will be statistically analyzed and results will be discussed with those found by other authors.

These results represent the first contribution to the knowledge of the growth of *Aphanopus carbo* in Northwest Africa.

9.2. Material and Methods

A total of 356 pairs of otoliths from 30ºN-26ºN zone (*Maroc 05-11* survey) were analyzed.

During the survey, otoliths were extracted, cleaned and stored dry in properly labelled plastic vials for its posterior analysis and study. Size range of examined exemplars varied between 62 and 135 cm total length.

Trying to improve otolith reading a polished test in whole otoliths was made, but due to the otolith characteristics (not flat and the polished is not exerted equal throughout the surface) it did not give good results and this technique was rejected.

Age was determined by interpreting growth rings on whole otoliths immersed in a black dish with water. Otoliths observation, under reflected light (episcopic), was made using a stereoscope microscope with either a 15x magnification or a

20x magnification, for the smallest ones. The ring associated to slow growth (hyaline) appeared dark due to the black bottom, whereas the ring associated to fast growth (opaque) appeared clear due to reflecting light. During observation, move luminous centre and change otolith position was a very useful tool in growth ring differentiation.

Descriptive statistical comparison (Wilcoxon test, P< 0.05) between right and left otolith weight demonstrated that no significant differences in the examined variable exist. Consequently, and to facilitate posterior analysis, following studies were carried out taking left otolith as reference, except if it was not available.

Length and width of otoliths was measure (mm) with a *Nikon AZ100* microscopic system connected to a *Nikon DS-5M* photographic. On the other hand, weight (g) was obtained using a precision Balance *Mettler Toledo- AG204* with a 0.01 mg precision.

The allometric relationships between otolith variables and between otolith and fish variables were established by sex.

In the otolith reading several aspects were taken into account: catch date, age, age-class, observation (from very well to very bad), conservation (from very well to very bad), reliability (from reliable to no reliable) and edge nature (hyaline or opaque) (Figure 9.2).

*4=VERY WELL,1=VERY BAD **A=VERY WELL, D=VERY BAD
***4=RELIABLE,1=NO RELIABLE ^H=HYALINE; O:OPAQUE

DATE	EXEMPL. Nº	AGE	AGE-CLASS	READING*	CONSERV.**	RELIAB.***	EDGE NAT. ^	OBSERVATIONS
21-nov-04	1							
21-nov-04	2							
21-nov-04	3							
21-nov-04	4							
21-nov-04	5							

Figure 9.2.- Reading sheet for *A. carbo*

We assumed that a set of an opaque and a hyaline zone corresponds to an annual increment. Fish is assigned to an age-class based on the date of birth assumed (1st of January). In this study, due to the presence in most individuals of a translucent edge and the date of capture (November-December), age

assigned will be equal to the number of annual increments observed minus one since it had been deposited during that year and before January 1st.

Each otolith was read with no knowledge of the specimen length. The age interpretation was established (location of the first ring and criteria of pseudo-rings consideration) and the readings for a given otolith were accepted depending on the reliability of the age estimation (only the first three levels of reliability were accepted).

However, it is important to notice that this growth study is just a preliminary analysis that will have to be completed with further studies including rings measurement and back-calculation.

The age-length relationship was established for males, females and all individuals using 2 cm size intervals. In addition, mean length-at-age evolution for males, females and all individuals was determined.

The growth parameters for males, females and for all individuals were estimated by means of a non-linear regression, using the Levenberg-Marquardt algorithm (SPSS Inc.).

Length-age pairs values and mean length-at-age from age-length keys for males, females and all individuals were fitted to the Von Bertalanffy growth function: $L_t=L_\infty\ (1-e^{-k\ (t-to)})$ where L_t is length (TL) at time t (years), L_∞ the asymptotic length, K the growth coefficient and t_0 the hypothetical time when the fish length is zero.

Differences between growth parameters by sex were tested with the Wilcoxon test using GraphPad Prism version 4.00 for Windows. The parameters were obtained from length-at-age of the estimated growth curve because we wanted to give higher importance to the individual growth variability.

9.3. Results

9.3.1. Age interpretation

Rings are more visible in the *postrostrum* and in the ventral side of the otolith. In the present study, the zone that allowed a better reading was the dorsal side of the *postrostrum* as in BASBLACK Project (growth zones are clearer in the later zone that in the rostral zone). It is therefore recommendable to examine several zones before choosing the one that allows the better observation pattern, e.g. the one that allows observing the entire existing ring.

The existence of a several pseudo-rings before the first ring was detected. This fact can lead to the misinterpretation of the first ring and even to some confusion when differentiating the second ring (Figure 9.3). Nucleus and first ring seems to be extended and more opaque than the rest of the otolith.

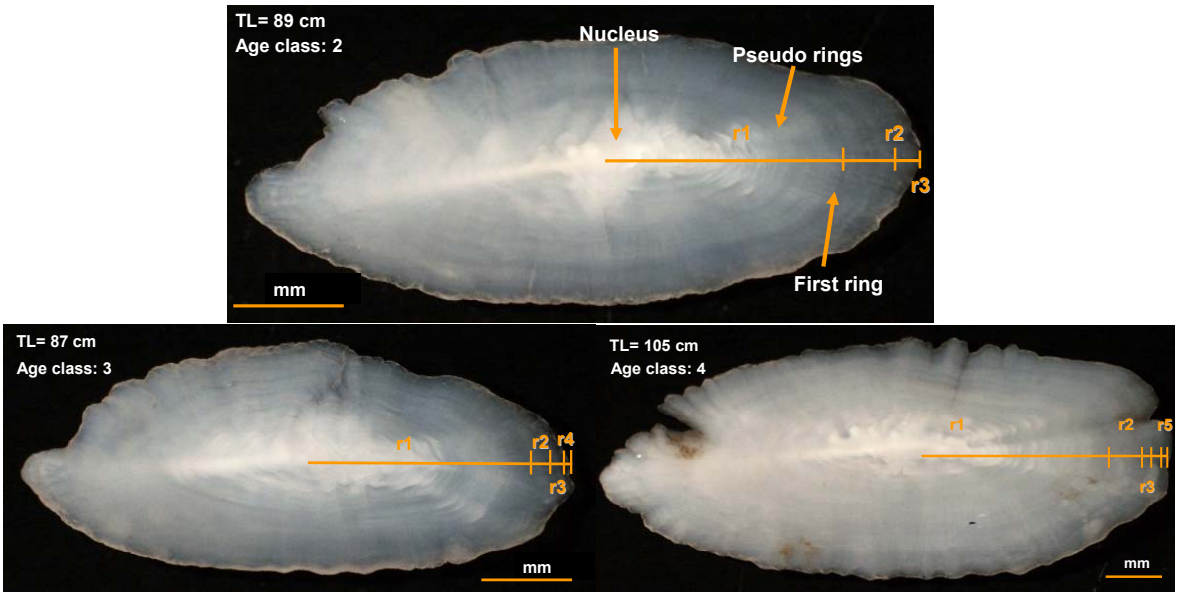

Figure 9.3.- Otolith interpretation pattern and some otoliths at different age-class

From the 356 otoliths available, only 302 were used to age determination. The remaining 54 otoliths (15.2%) were rejected because they were either broken, or too much calcified or not calcified enough, or in bad conditions for reading.

Moreover, 50 otoliths were further rejected due to a low reliability (level 1) leading to a final number of 252 otoliths used in age determination and growth study (Figure 9.4).

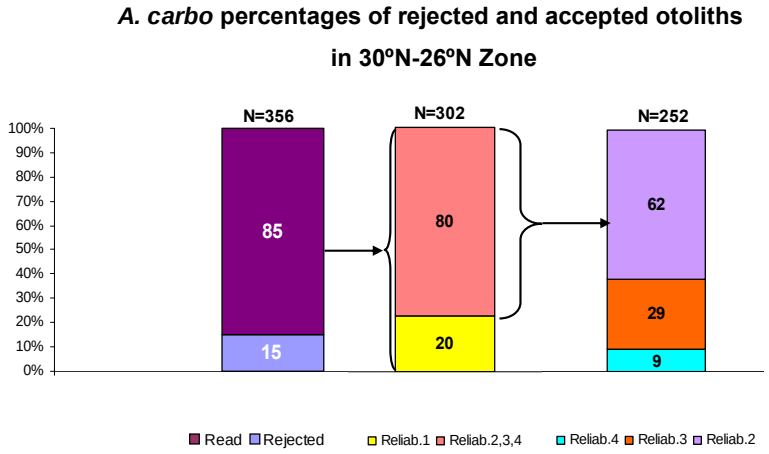

Figure 9.4.- Percentages of rejected and accepted otoliths on reading process

Regarding the otolith's edge, 94.7% of the samples presented hyaline edge for the sampling period (November-December). The remaining otoliths (5.3%) were included within the opaque edge group. Percentages of hyaline and opaque edge are given in Figure 9.5.

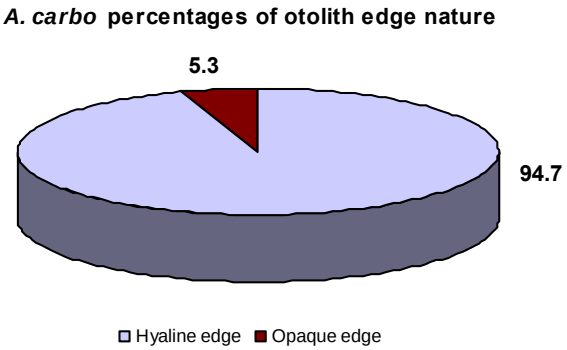

Figure 9.5.- Percentage of hyaline and opaque edge

9.3.2. Allometric relationships

Results of allometric relationship are presented in Figure 9.6 and 9.7.

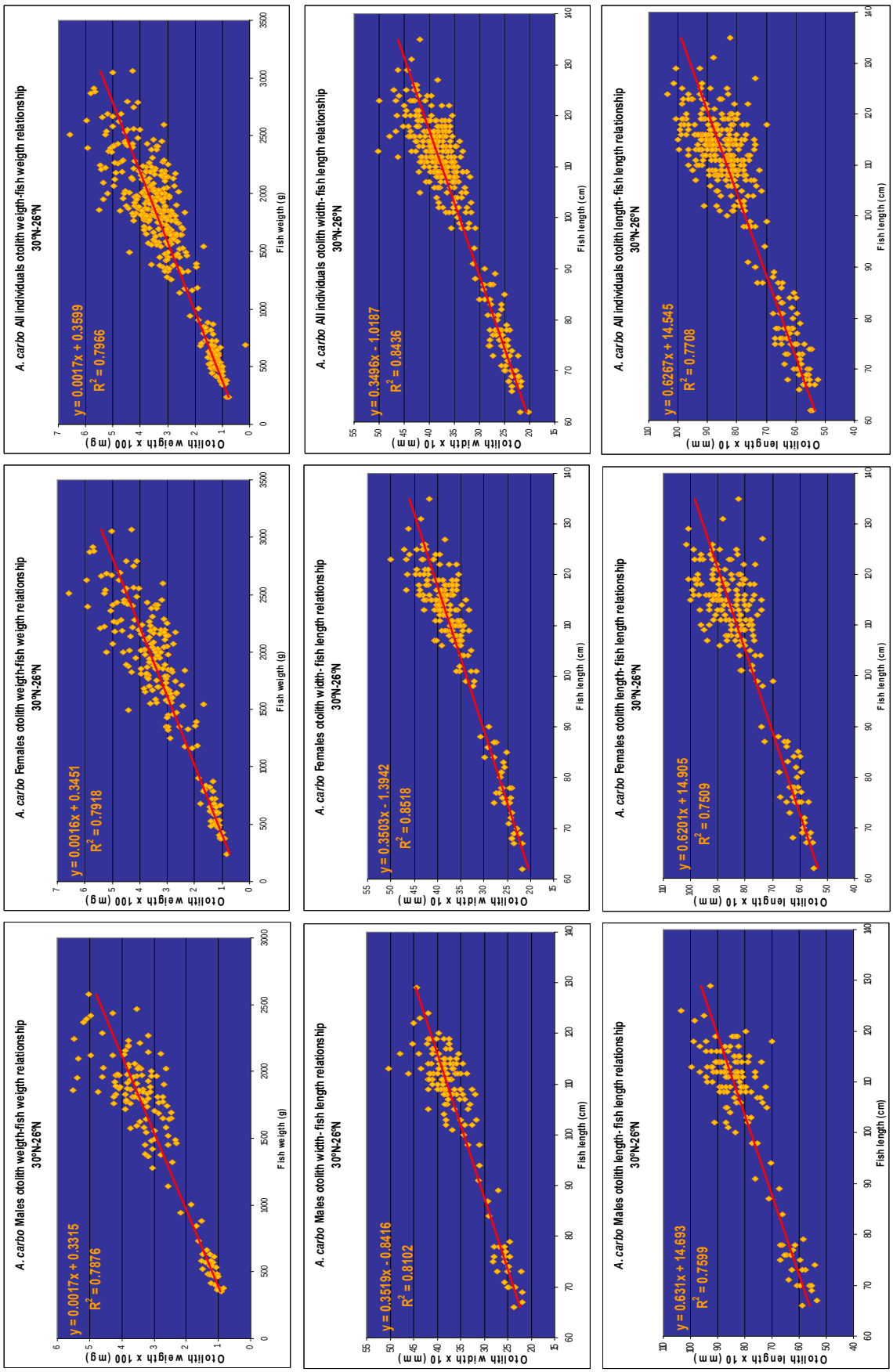

Figure 9.6.- *A. carbo* allometric relationships between otolith weight and fish weight, otolith width and fish length and otolith length and fish length for females, males and sexes together

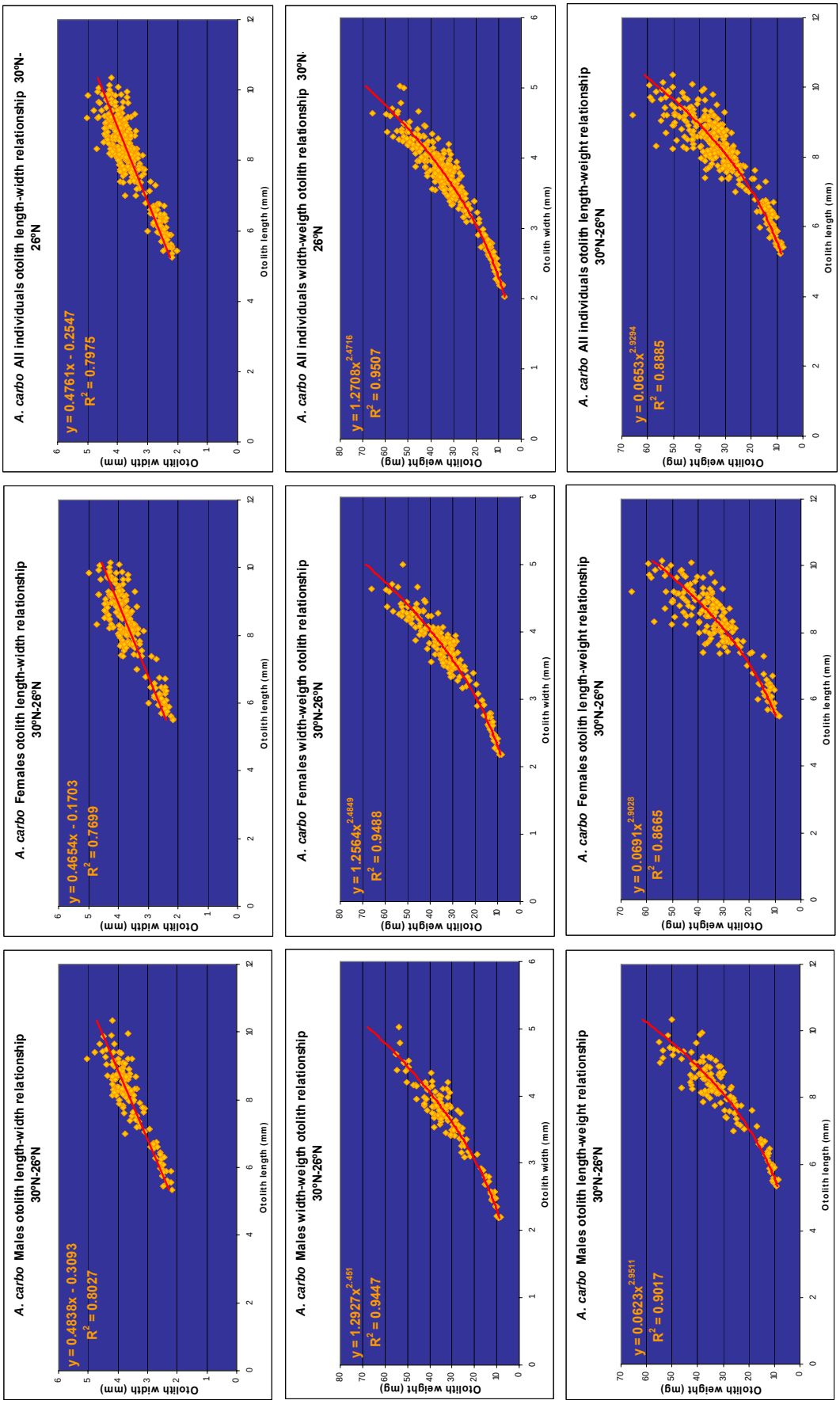

Figure 9.7.- *A. carbo* allometric relationships between the otolith's length and width, otolith's width and weight and otolith's length and weight

A. carbo regressions analyses indicates that a high correlation between otolith variables exist ($0.77<R^2<0.95$), being width and weight otolith the best correlated variables ($R^2=0.95$). By sex, correlation was always superior for males than females, except in the width-weight otolith relationship.

In the allometric relationships between otoliths and fish variables, a high correlation also exist ($0.76<R^2<0.85$), being the allometric relationship between otolith width and fish length the one with the higher determination coefficient ($R^2= 0.85$). Regarding these relationships but by sex, it can be seen that females present higher correlations than males except in otolith length-fish length relationship.

9.3.3. Age - Length relationship

Age-length keys for *Aphanopus carbo* males, females and all individuals for 30ºN-26ºN zone are given next (Table 9.1).

Age range in the present study varied between 1 and 9 years and the size range varies between 66 and 124 cm. Both sexes present the same age range (1-9) in a similar size group range (66-122 cm, 66-124 cm).

The worst represented age-class (less than 10 individuals) was the age-class I, VIII and IX for females; the age-class I, VI, VIII and IX for males and the age-class I, VIII and IX for all individuals.

The best represented age-class were age-class IV, V and VI with percentages ranging between 62% and 64%. Of these, the most representative age-class for males, females and all individuals was age-class V with percentages between 23% and 24%.

Table 9.1. Age-length keys for *A. carbo* males, females and all individuals in 30ºN-26ºN

MALES

Age/Length	I	II	III	IV	V	VI	VII	VIII	IX	N
60										
62										
64										
66	2									2
68	1	3								4
70		2								2
72		1	2							3
74		2	1							3
76		1	2							3
78			2							2
80										
82										
84				1						1
86			1							1
88			1							1
90		1								1
92				1						1
94										
96										
98				1						1
100			1		1				1	3
102			1	3	2					6
104			1			2		1		4
106			1	3	2	2	1			8
108			1	2	3	1	1			8
110				2	4	3			1	10
112				3	8	1	2			14
114			2	2	1	4	3			12
116				1	1	3				5
118				2	3	2				7
120										
122				1			1			2
124										
126										
128										
130										
n	3	10	16	22	25	18	7	1	2	104
mean (cm)	67.7	74.0	91.5	108.8	111.4	112.7	114.7	105.0	106.0	
SE	0.7	2.1	4.0	1.9	1.0	1.1	1.6		5.0	

FEMALES

Age/Length	I	II	III	IV	V	VI	VII	VIII	IX	N
60										
62										
64										
66		2								2
68	2	2								4
70	1									1
72	1	1								2
74	1	4								5
76			4	1						5
78		1								1
80		1		1	1					3
82		1	2							3
84			2							2
86			3	1						4
88			2							2
90										
92										
94										
96		1								1
98				2						2
100		1	1	1						3
102										
104					4	1				5
106				2	2	4	1			9
108			1	4	4	1	1			11
110			1	3	2	1	1			8
112				3	3	2	3			11
114			1	4	9	3	2		1	20
116				2	3	6	2			13
118				4	3	4	3			14
120				1			1		1	3
122				1	1	2				4
124				1	1	1				3
126										
128										
130										
n	5	14	17	31	33	25	14		2	141
mean (cm)	71.4	77.6	89.4	109.8	112.2	114.9	114.9		118	
SE	1.2	2.8	3.0	2.0	1.3	1.1	1.1		3	

ALL INDIVIDUALS

Age/Length	I	II	III	IV	V	VI	VII	VIII	IX	N
60										
62										
64										
66	2	3								5
68	3	5								8
70	1	2								3
72	1	3	2							6
74	1	6	1							8
76		1	6	1						8
78		1	2							3
80		1		1	3					5
82		1	2			1				4
84			2	1						3
86			4	1						5
88			3							3
90		1								1
92				1						1
94										
96		1		1						2
98				4						4
100		1	2	1	1				1	6
102			1	3	2					6
104			1		4	3		1		9
106			1	5	4	6	1			17
108			2	6	7	2	2			19
110			1	5	6	4	1		1	18
112				6	11	3	5			25
114			3	6	10	7	5		1	32
116				3	4	9	2			18
118				6	6	6	3			21
120				1			1		1	3
122				2	1	2	1			6
124				1	1	1				3
126										
128										
130										
n	8	26	33	55	60	44	21	1	4	252
mean (cm)	70.0	75.6	90.4	109.0	110.8	113.3	114.8	105.0	112.0	
SE	1.0	1.7	2.4	1.4	1.1	1.0	0.9		4.2	

Mean length-at-age evolution for males, females and all individuals are presented in Figure 9.8. It can be observed that mean length increase progressively with the age, as it was expected. Females present, generally, higher mean length-at-age than males. However, in the age-class VIII and IX, a slightly decrease in size exist due to the scarce number of individual sampled.

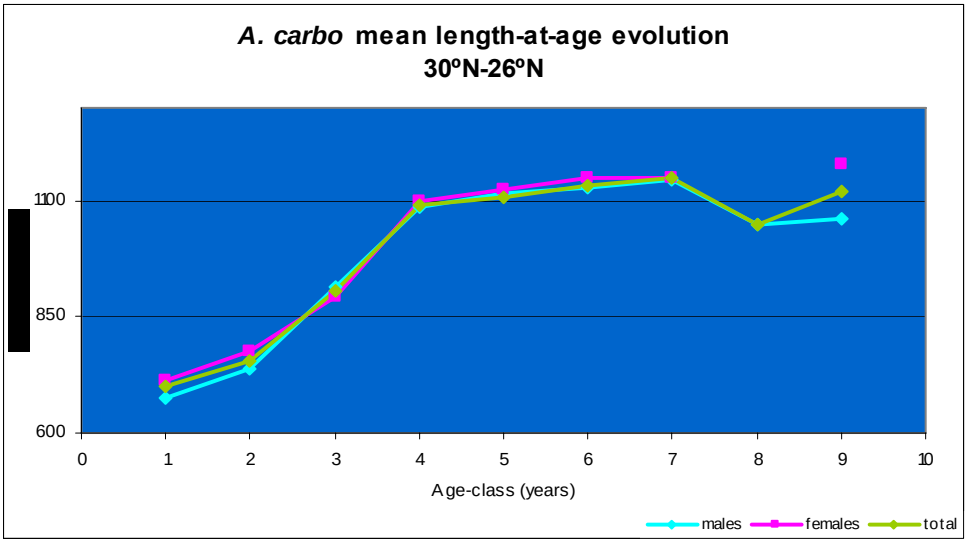

Figure 9.8.- *A. carbo* mean length-at-age

In the first years, this evolution is more pronounced due to be the period of maximum growth. It is important to notice that no female in age-class 8 was determined.

9.3.4. Growth parameters

The growth parameters, by sex and sexes combined were obtained by length-age pairs of values and mean length-at-age (from age-length keys), and other geographical areas are given in Table 9.2.

Table 9.2.- *A. carbo* growth parameters in different geographical areas

AREA	SEX	K	t_0	L_∞ (cm)	n	Age range	Size range (cm)	r^2	Source
Length -age pairs of values	♂	0.469	-0.385	119	104	I-IX	66-124	0.63	Present study
	♀	0.377	-0.850	125	141	I-IX	66-126	0.62	
	total	0.415	-0.645	122	252	I-IX	66-126	0.60	
Mean length-at-age	♂	0.509	-0.627	113	104	I-IX	66-122	0.80	Present study
	♀	0.324	-1.419	125	141	I-IX	66-124	0.92	
	total	0.440	-0.932	115	252	I-IX	66-124	0.84	
Canary Islands	♂	0.263	-3.507	141	102	II-VIII	108-133	0.85	Pajuelo *et al.* (2008)
	♀	0.196	-4.647	148	196	II-XII	98-148	0.91	
	total	0.200	-4.580	148	298	II-XII	108-148	0.91	
Portugal Mainland (Sesimbra)	total	0.110		145	1042		72-134		Martins *et al.* (1989)
	total	0.177	-1.793	133	245	IV-XI	84-122	0.98	Carvalho (2001)
Madeira	♂	0.160	-3.270	155	789	0-VIII	54-151		Morales-Nin & Sena-Carvalho (1996)
	♀	0.260	-2.080	142					
	total	0.251	-2.284	139					
	total	0.180	-1.757	132	104	VIII-XV	107-136	0.99	Carvalho (2001)
	total	0.364	0.649	123	167	IV-XV	64-124	0.97	Barreto (2005)*
	total	0.120	-5.336	137	349	IV-XV	84-136	0.97	Barreto (2005)**
NE Atlantic	total	0.177	-1.793	133	603	II-XII	60-150		Anon. (2000a)

* age obtained by otolith rings interpretation

** age obtained by otolith weight

In our study area, L_∞ values vary between 115 and 125 cm and were always superior in females than in males. As consequence, K values were higher in males than in females.

Regarding the growth coefficient (k) it can be seen that its value varied between 0.42 and 0.44. In all cases, growth coefficient (k) in males was superior to females.

Growth parameters values obtained by both methods (length-at-age pairs of values and mean length-at-age) were similar, even almost equals in females, but the best adjustment (higher R^2) was obtained with mean length-at-age. This fact is due to the own characteristics of the method since it deals with data adjusted to a medium value (smoothing method). Wilcoxon test results ($P<0.05$) shows that there is a significant difference between females and males in growth.

Evolution of length-at-age pairs of values and Von Bertalanffy growth curves for males, females and all individuals are presented in Figure 9.9.

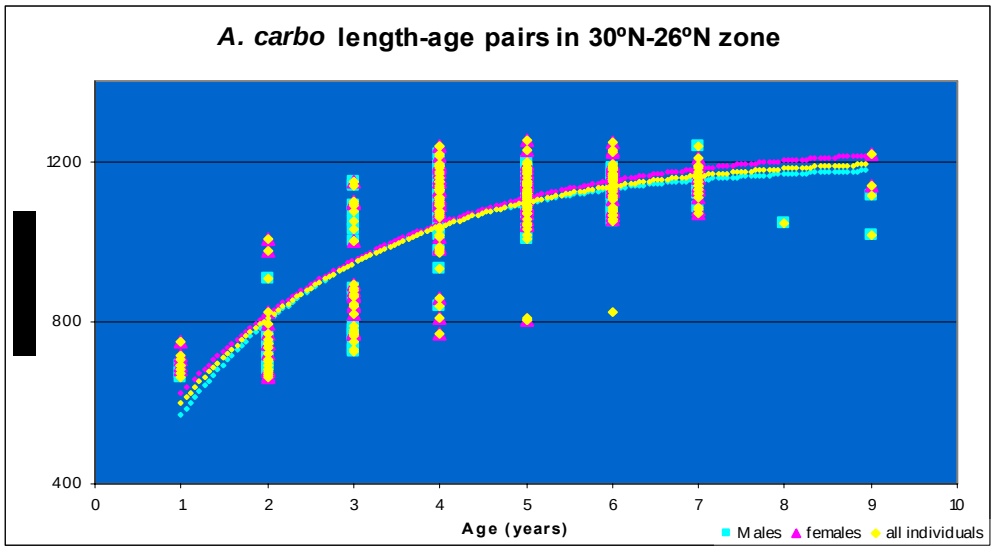

Figure 9.9.- Length-at-age pairs of values evolution

9.4. Discussion

According to all previous studies carried out on *A. carbo*, sectioned otoliths gave always older ages than whole otoliths due to the misinterpretation of false rings. In a previous paper on the intercalibration of otolith readings (Morales-Nin *et al.*, 2002) it was suggested that whole otoliths should be used for age readings since the authors believed that sectioned otoliths could result in age overestimation. Nevertheless, the same authors concluded that an effort to study sectioned otoliths should be done since they believed that, in the future, they might lead to better results. Therefore, in this first contribution to the knowledge of *A. carbo* growth in NW Africa, it seems well justified our choice of using whole otolith in black scabbardfish age determination.

The main difficulties we faced were to locate the first ring and the interpretation of the marginal growth zones. This same situation has been encountered in BASBLACK Project (Anon., 2000a) and in Morales-Nin & Sena-Carvalho (1996) and Morales-Nin *et al*. (2002). These studies explained that the interpretation of the first ring was one of the main problems due to the variability of the nuclear area morphology. The nuclear zone was opaque with some rings inside and the last one close to the edge. BASBLACK Project explained that frequently faint 2-3 rings were visible in the central zone followed by a more marked one, considered

as the first increment. However, there was a considerable variability inter areas and in the same sampling locality.

The general interpretation criteria of following a ring all around the otolith to determine if it was a true ring could not be applied in this study. Frequently, it is impossible to follow a ring all around. This fact has been also encountered in other studied areas. The zone with clearer rings, in our case, seemed to be the dorsal side of the *postrostrum* as in BASBLACK Project (Anon.2000a where the authors concluded that the growth zones were clearer in the later zone than in the *rostral* zone. Also, according to Morales-Nin *et al.* (2002) growth increments could only be located in the dorsal and ventral otolith zones, whereas in the *rostrum* and *antirostrum* the increments were unclear and split in multiple rings.

Nothing is known about early life stages of this species, but the otolith structure suggest that they might have transitional changes similar to the juvenile habitat migration of flatfish and Gadidae, probably passing from being pelagic larvae to benthopelagic juvenile and adults (Morales-Nin *et al.*, 2002).

The highest proportion of hyaline edge founded in our study (November-December) also appeared in the specimens from Madeira waters, where hyalines edge are dominant during the same months, a fact that may be related to the reproductive period in this area (Morales-Nin & Sena-Carvalho, 1996). Thus, in Madeira waters and throughout the year, most otoliths presented a higher percentage of opaque edge while, in November-December, the hyaline edge percentage increased. In BASBLACK Project (Anon., 2000a) the same tendency was observed, although there was a big variability due to the low number of samples obtained. In our case, it would be necessary monthly samples to complete this study throughout a year.

The age range (I-IX) found in the present work is included in the age range found in other geographical areas, although we recorded age-class I that is not present in the majority of studies. It is important to notice that the number of individuals used in this work is in an intermediate level comparing to the other areas and, the size range is quite ample with the presence of specimens of small sizes which are very important in growth studies. The studies carried out by Kelly

et al. (1998) and Clarke *et al*. (2003) presented the higher age found (32 years), but it is important to notice that these two studies were made using sectioned otolith.

In general, low K values (0.1-0.2) determined for other geographical areas indicate that black scabbardfish is a slow growing species. According to Nakamura & Parin (1993) and to duplicate the population number it would be necessary between 4.5 and 14 years (K=0.11).

The k values determined in the present work were higher than those found in other areas. These values could be explained due to the oceanographic conditions present in the study area, recognized as one of the fourth most important upwelling zone of the world. Comparing our k values with those from Canary Islands (Pajuelo *et al.*, 2008) it can be observed that in Canaries this k value is lower. But this could be influenced by the absence of small individuals in the Canaries samples that would present a higher growth ratio and that would increase its growth coefficient. In addition, Morales-Nin *et al.* (2002) reported a high growth rate for this species as a result of very favourable food conditions the species encounters in the Atlantic. Also, in Madeira and Sesimbra Carvalho (2001) found a low K value, that could be also explained by the absence of individuals smaller than 84 cm in the samples.

The significant differences in growth parameters between sexes founded in our study were expected, since we have already observed this phenomenon (females reach larger sizes) in previous chapters (Size and Length-weight relationship). This fact is also registered in Canary Islands where Pajuelo *et al.* (2008) found that significant differences were found between mean length-at-age of males and females and between the von Bertalanffy growth curves for separate sexes. As in our case, difference in growth by sex, with females reaching slightly greater length than males has also observed in waters off Madeira (Morales-Nin & Sena-Carvalho, 1996).

10. CONCLUSIONS

* In this report, black scabbardfish individuals between Tangier and Cape Blanc (35ºN-21ºN) were analyzed. *A. carbo* was distributed between 700 and 1 700 m but it was more abundant between 800 and 1 400 m, decreasing progressively towards deeper waters. The highest catches were obtained between 1 000 and 1 200 m.

* In spite of the possible effects of temporary variations along the different years (2004, 2005, 2006), geographical areas (35ºN-30ºN, 30ºN-26ºN, 26ºN-21ºN) and depths (500 to 2 000 m, 500 to 2 000 m, 200 to 2 000 m), the catches of *Aphanopus carbo* were higher between 30ºN-26ºN and lower between 26ºN-21ºN.

* An increase of size with depth was found. The southern zone (26ºN-21ºN) presented the highest proportion of small individuals (immature), which occurred from 800 to 1 300 m. On the contrary, in the north and central zones (from 35ºN to 26ºN) the highest proportion of immature occurred between 800 and 1 000, mainly from 800 to 900 m.

* Females were more numerous than males and, although no significant statistical differences were found, females' mean length was superior to males. Concerning sex ratio, the number of females was higher than males except in the southern zone (26ºN-21ºN) where the sex-ratio was 1:1. The females' proportion increases considerably from 100-110 cm onwards. Sex ratio analysis by size range and depth strata indicated no determined pattern either in same latitude or in same strata at different latitudes.

* Due to the seasonality of the samples, it was impossible to determine a precise spawning period, a length at first maturity or massive maturity. Nevertheless, the high percentages of males and females in stage II and III-IV, and the low percentages of individuals in stage V founded in this study seem to indicate that individuals were preparing to spawn probably in the beginning of December.

* Spawning individuals were always present in higher numbers in males, and females presented always a higher percentage of pre-spawning individuals. This could indicate that males attain the spawning condition earlier than females.

* Regarding length-weight relationship, females reach higher weight and length values than males. Moreover, statistical differences between males and females in the length-weight relationship were founded. *A. carbo* showed a positive allometry in the growth of males and females in the study area. Thus, *A. carbo* weight increase is proportionally higher than length increase.

* In spite of this is the first contribution to the knowledge of *A. carbo* growth in the North West Africa, the observation of whole otolith was the best method for age determination. Dorsal side of the *postrostrum* of the otoliths seems to be the zone with better visibility of growth rings. However, in most of the cases it was impossible to follow a growth ring all around the otolith.

* The existence of a great size of the first ring with pseudo-rings was detected. Because of that, the location of the first ring was one of the main problems due to the variability of the nuclear area morphology.

* The majority of the otoliths presented hyaline edge as the end of the annual growth ring formation. Otolith width-otolith weight and otolith width-fish length were the best correlated relationships.

* For both males and females, individuals were aged from I to IX years-old. The most representative age-class for males and females was age-class V.

* Males presented higher growth coefficient and less asymptotic length than females. On the other hand, statistical differences in growth for males and females were detected.

* In general, growth coefficient values of *A. carbo* from North West Africa were superior to the other geographical areas analysed, probably due to the oceanographic conditions of the study area, recognized as one of the four most important upwelling zones of the world.

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